Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

Estimating Carbon Sequestration Cost Function for Developing Countries

Mohammad Nur Nobi

Master's thesis · 30 hec · Advanced level
Environmental Economics and Management - Master's Programme
Degree thesis No. 782 · ISSN 1401-4084
Uppsala 2013

Estimating Carbon Sequestration Cost Function for Developing Countries

Mohammad Nur Nobi

Supervisor: Ing-Marie Gren, Swedish University of Agricultural Sciences, Department of Economics

Examiner: Yves Surry, Swedish University of Agricultural Sciences, Department of Economics

Credits: 30 hec
Level: A2E
Course title: Degree Project in Economics
Course code: EX0537
Programme/Education: Environmental Economics and Management, Master's Programme
Faculty: Faculty of Natural Resources and Agricultural Sciences

Place of publication: Uppsala
Year of publication: 2013
Name of Series: Degree project/SLU, Department of Economics
No: 782
ISSN 1401-4084
Online publication: http://stud.epsilon.slu.se

Key words: Carbon Sequestration, Carbon Sequestration Cost, Emission Reduction, Deforestation Halted, Afforestation/Reforestation, Sustainable Agricultural Practice, CDM, Per Capita GDP

Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

Estimating Carbon Sequestration Cost Function for Developing Countries

Mohammad Nur Nobi
Swedish University of Agricultural Sciences (SLU)

Abstract

Carbon sequestration is considered as the cost effective way of reducing carbon dioxide emission and other greenhouse gases. This study estimated the carbon sequestration cost function considering land use change in developing countries. Using the instrumental variable method, this study found that the percentage change in the cost due to the percentage change in carbon sequestration is almost unitary. The result also shows that the presence of Clean Development Mechanism (CDM) project in a country and per capita GDP in purchasing power parity (GDP, ppp) have positive influence on the carbon sequestration cost function. The marginal cost calculated from the total cost function representing the unit price of carbon dioxide is very low compared with the marginal abatement cost of the developed countries but equals the price at the European CO_2 emission trading market.

Table of Contents

List of Tables

List of Figures and Graphs

List of Acronyms

Annex I	Annex I countries listed in Annex I in UNFCCC and Annex B in Kyoto Protocol
C	Carbon
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
CO_2e	Carbon dioxide Equivalent
Cop 6	6th Conferences of the Parties to UNFCC, The Hague, November 2000
Cop 7	7th Conferences of the Parties to UNFCC, Marrakesh, October-November 2001
EEC	European Union Countries
EIA	Energy Information Administration
EUA	European Union Allowance
EUETS	European Emission Trading System
FAO	Food and Agriculture Organization
FCI	Forest Carbon Index
FOC	First Order Condition
GHG	Greenhouse Gas
GIS	Geographic Information Systems
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
LUC	Land Use Changes
LULUCF	Land Use Land Use Change and Forestry
N	Nitrogen
Non-Annex I	Countries listed in Non-Annex I in UNFCCC
NPV	Net Present Value
OEC	Other OECD Countries
OECD	Organization of Economic Cooperation and Development
PPP	Purchasing Power Parity
REDD	Reducing Emission from Deforestation and Degradation

RFF	Resources For the Future
TEEIC	Tribal Energy and Environmental Information Clearinghouse
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USD	United States Dollar
USEIA	United States Energy Information Administration

Acknowledgements

I would like to express my sincere gratitude and honour to my supervisor **Dr. Ing-Marie Gren** (Professor, Department of Economics, Swedish University of Agricultural Sciences, Uppsala, Sweden) for her continual guidance and suggestions throughout the preparation of this thesis. It was supposed to be quite impossible to accomplish this thesis without her insightful directions and cordial assistantship. I am thankful to **Dr. Yves Surry** (Professor, Department of Economics, Swedish University of Agricultural Sciences, Uppsala, Sweden) for his meaningful and practical guideline to make the thesis a success.

I am grateful to **Dr. Sandra Brown** (Senior Scientist, Winrock International, USA) for her appreciable job rendering kind help in getting necessary data analysis used in a paper by Niles et al. (2002).

I am also thankful to Mamtaj Uddin Ahmed (Assistant Professor, Department of Public Administration, University of Chittagong, Bangladesh) for taking pain to proof read the writing from reader's view and Md. Abdur Rahman Forhad (Assistant Professor, Department of Humanities and Social Sciences, Dhaka University of Engineering and Technology, Gazipur, Bangladesh) for his psychological attachment in the preparation of the thesis.

Finally, I feel proud to remember my beloved late mother Tajia Begum who first enlightened me in the world and inspired me as an eternal vigilance not only for the lifespan study but also for every good work in my life.

Mohammad Nur Nobi
March, 2013

Chapter-1: Introduction

Carbon sequestration is the method by which carbon dioxide (CO_2) is captured and stored that helps reducing carbon emission in the atmosphere. According to Carbon Finance carbon sequestration refers to-, *"The process of removing carbon from atmosphere and depositing it in a reservoir"* (Carbon Finance, 2011, p. 39). World Soil Resources, quoted from Resources For the Future (RFF) *"Generally refer[ring] to capturing carbon- in a carbon sink, such as the oceans, or a terrestrial sink such as forests or soils - so as to keep the carbon out of the atmosphere"(*World Soil Resources Report-92, 2000, p. 8).

It is an alternative way of reducing carbon dioxide emission reduction and can be a component of emission trading approach where greenhouse gas emissions are capped and then used to allocate the emissions among the group of regulated sources. Carbon sequestration helps to achieve the goal of emission reduction in a cost effective way through the carbon market mechanisms. The carbon market mechanism drives industrial and commercial processes in the direction of low emissions or less carbon intensive approaches comparing to "business as usual" emission into the atmosphere. There are three methods used for carbon reduction into the atmosphere; efficiency and conservation, carbon-free and reduced carbon energy sources and carbon capture and sequestration (TEEIC, 2012). By using efficiency and conservation energy reduces carbon emission. The carbon free and reduced carbon energy includes the solar power, wind power, geothermal and nuclear power. Finally, carbon capture and sequestration which involves capturing and storing carbon dioxide within plants and soil (TEEIC, 2012).

Carbon sequestration depends on some driving factors like land use and land use change. It is expected to be increased positively with the expansion of size of the forest land. Since carbon sequestration/Green House Gas (GHG) mitigation projects generate credits, this approach can be used to finance in the carbon sequestration projects between trading partners around the world. This is explained in article 12 of Kyoto Protocol where Annex I countries can earn credits by investing emission reduction projects in developing countries to meet domestic GHG emission quotas through Clean Development Mechanism (Bloomfield and Pearson, 2000). At present many companies are involved in the sale of carbon credits to commercials and individuals who are willing to lower their carbon footprint at voluntary basis. The carbon off-setters can purchase the credits from an investment fund or a carbon development company that aggregates the credits from individual projects. An exchange platform is used to trade by the parties, such as the Carbon Trade Exchange which is similar to a stock exchange for carbon credits or European Emission Trading System (EUETS). The quality of the credits is based on the validation process and sophistication of the fund or development company that acted as the sponsor to the carbon project. This sponsorship is reflected in the carbon price while voluntary units with lower price and the units sold through the rigorously validated Clean Development Mechanism (CDM) (Hay et al. 2007**)** with higher price.

By the Kyoto Protocol (1997), the industrialized countries (Annex I) set a goal of reducing CO_2 by 2010. To achieve that target they have to reduce on an average 5.2% (based on the measurement of the year 1990) of their overall GHG emission within the period of 2008 to 2012. On the other side no mandatory obligation was set for Non-Annex I countries (Kapoor and Ambrosi, 2006). At present 39 developed countries which need to reduce their carbon emission because of high growth and emission level (Smith and Scherr, 2002). But the reduction of emission is costly to developed countries. In contrast, developing countries (Non-Annex I) having no reduction target can reduce CO_2 emission with lower cost through carbon sequestration in their terrestrial forest lands. As a result, carbon sequestration in developing countries decreases the cost of emission reduction for developed countries and generates an extra source of foreign earnings for them (Ellerman et al, 1998). Thus the cost of carbon sequestration has importance to achieve the goal of emission reduction and to the investors (land owners) for profitability. Many studies argue that the forest based carbon sequestration is cost effective but if the indirect costs of the carbon sequestration are calculated then the carbon price is little bit lower compared to the abatement cost of carbon by countries mentioned in Annex I (Ellerman et al, 1998).

The concept of carbon sequestration is a result of increasing awareness of the need for controlling emissions. The IPCC (Intergovernmental Panel on Climate Change) has observed that global temperature increases due to emission of GHGs and thus concentration of GHGs in the atmosphere needs to be stabilized to protect global disasters. Considering this issue UNFCCC has assigned and adopted a protocol named ‘The Kyoto Protocol’ on 11 December 1997 in Kyoto, Japan though the protocol came to effect on 16 February 2005. Till September 2011 almost 191 countries have signed and ratified the protocol but USA is the only country which did not ratify the protocol yet (UNFCCC).

All Annex I member countries (37) who have signed and ratified the Kyoto Protocol come to a consensus that they have to reduce GHGs and accordingly they decided to reduce four GHGs (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride) and two groups of gases (hydro fluorocarbons and per fluorocarbons). At negotiations, Annex I countries (including the USA) collectively agreed to reduce their GHGs emission by 5.2% on average from the year 2008 until 2012. Measurement and calculation of emission reduction will be based on the annual emission of the year 1990, which has been recognized as the base year. Since the USA has not ratified the protocol, the collective emission reduction (from the standard of the year 1990) target of 5.2% declined to 4.2% (IPCC).

Though the protocol has emphasized to reduce the GHGs but simultaneously it allows some ‘flexible mechanisms’, includes emission trading, the CDM and Joint Implementation (JI) which are now known as carbon market. These mechanisms create opportunity for Annex I countries to meet their GHGs emission limit through purchase reduction credits from elsewhere in the world. The methods of purchasing GHGs include financial exchanges, projects which reduce emission in non-Annex I countries and from Annex I countries with excess credit allowances. The ultimate goal of these flexible mechanisms defined under the Kyoto Protocol was to lower the overall costs of achieving its emission targets. These mechanisms enable parties to achieve emission reduction or to remove carbon from the atmosphere cost-effectively in other countries. While the cost of limiting emission varies considerably from region to region, the benefit for the atmosphere is in principle the same, wherever the action is taken (UNFCCC, Market Mechanism under Kyoto Protocol). As a result, projects for carbon sequestration were encouraged in Non-Annex I countries and using this flexible mechanisms Annex I countries can reduce emission by trading from developing countries that are lesser emission or has the carbon stored in forests areas.

For carbon trading, developing countries are considered to receive credits from developed countries under flexible mechanisms which are helpful for carbon sequestration. But after Cop 6 and Cop 7, increased range and scale of forestry and land uses have changed credit system of Annex I countries which reduced the availability of credit to developing countries and decreased their benefits of emission trading. As a result, it declined the standard of livelihood by increasing regulatory costs of investment in rural areas in developing countries (Bettelheim and Origny, 2002). Thus the cost of carbon sequestration has influential effects on land use change in favor of carbon sequestration in developing countries. Usually, a country (in practice farmers or landowners) will use its land for carbon sequestration if it finds the sequestration less costly. It will also consider the unit price of carbon to be high enough to supply more carbon sequestration. In contrast, as buyer, developed countries will look for carbon reduction through sequestration if it is less costly or cheaper comparing the other means of reduction or abatement costs. Thus the cost of carbon sequestration is very important to combat the climate change effect caused by carbon dioxide emission.

The purpose of this study is thus to estimate the carbon sequestration cost function for developing countries as it may plays a vital role in climate change policy. Since the tropical forest can be used as the sink of carbon sequestration, this study will consider the LUC (Land Use Changes) pattern on carbon sequestration in estimating the cost function.

The global concern for reducing carbon emission has enhanced the carbon sequestration as a cost effective measure. Though it is assumed as a cost effective measure but how effective it is? Is it a profitable sector to the landowners? And does this carbon sequestration effectively benefit the developing countries as supplier countries? To get answers of these questions we need to know the nature of carbon sequestration cost function. As a result, this thesis is intended to estimate the carbon sequestration cost function for developing countries so that we could know the merits and demerits of carbon sequestration which hopefully can combat negative effects of climate change. While estimating the carbon sequestration cost function this study used data on a sample of 58 countries from different sources.

The remaining of this study is organized as follows. In chapter 2, relevent literatures are reviewed, chapter 3 demonstrates the theoretical background of the thesis, chapter 4 consists of the determinants of the cost of carbon sequestration, chapter 5 covers the data sourecs and analysis, chapter 6 focuses on the econmetric models and results with different hypothesis tests, chapter 7 discusses the comparison of the results and findings with previous estimates and current market scenario, and final section has included a concluding remark.

Chapter-2: Literature Review

Many previous studies have analyzed the carbon sequestration function as a cost effective method of emission reduction. For the purpose of this thesis some of the important studies are reviewed.

Bloomfield and Pearson (2000) have argued that the land use, land use change of reducing deforestation rate, increasing land to forest plantations, reforestation, agro forestry, improving the management of forests and agricultural areas can help reduction of GHG emission by increasing carbon storage. They have indicated productive capacity of land, financial consideration of the land owners and environmental concern as determinants of land use decisions. In contrast, for carbon benefit they have stated that it would be either increasing carbon storage or use of wood as bio fuel. In this paper they have examined various options and trade-off that the developing countries face in using land use and land use change activities. The options they considered are reforestation, plantation, agro-forestry and halting deforestation from different previous studies. Then they have analyzed the existing estimates of offset potential and assessed how realistic those estimates were according to the constraints and driving factors. Their study based on the eight previous studies on regional and country-level estimates of land use and land use change offset potential. The regions cover Africa, Asia and tropical America particular emphasis on tropical Non-Annex I countries were discussed in all studies. Above and below ground biomass and soil, soil and fossil fuel offset were considered as carbon pools whereas, reforestation, plantation, agro-forestry, improved management of cultivable land and production of energy crops were activities. In case of reforestation offset potential varies from minimum 5.7 billion ton to maximum 12-29 billion ton per year, offset potential for slowing deforestation ranges from minimum 4.5 billion ton to maximum 11-21 billion ton per year, plantation ranges from min 2-5 billion ton to maximum 16.4 billion ton, improved management of cultivated land and energy crops 0.2-0.7 billion ton per year.

Stavins (1999) has discussed the revealed preference method using econometric model for estimating carbon sequestration cost function. He tried to address each problem for why land owners' behavior is not well predicted in engineering or least cost methods. The problems he suggested are i) irreversible investment due to uncertainty make the option values important in land use changes; ii) forest land may have non-pecuniary returns to the land owners; iii) decision making inertia; and iv) probability of market benefit or cost of alternative land uses. Then, he intended to focus on econometric analyses of land use for getting an estimate of marginal cost of carbon sequestration. Using panel data for 36 counties of Arkansas, Louisiana and Mississippi of USA from 1935 to 1984, he estimated the parameters with non-linear least squares estimators. He then found that marginal costs of carbon sequestration increases gradually until it reaches $66 per ton of carbon where carbon sequestration reaches 7 million ton above the baseline sequestration 4.6 million ton. He also noticed that the marginal cost follows a linear trend. The same result also has obtained by Newell and Stavins (1999). They estimated the marginal cost of carbon sequestration observing land owners' behavior using engineering or least cost approaches. They found that the cost of carbon sequestration can be greater if the trees are harvested periodically rather than permanently; higher discount rate imply a higher marginal cost; higher agricultural price leads higher marginal cost or reduces sequestration and slow downed deforestation can sequester carbon at lower cost than reforestation. In a recent study on cost of USA carbon sequestration, Stavins and Richards (2005) have shown that the cost of per ton of CO_2 ranges from $7.5 to $22.5 while it ranges from $30 to $90 in an extensive program.

A comparison of studies of USA Energy Information Administration (EIA) found that in 2020 cost of last ton of carbon is $52 if it is reduced in the USA and it is only $31.75 if reduction comes from global market (Kopp, 2011). But global attempt can reduce the cost significantly which is shown by a recent study that 100-125 million tons of deforestation based carbon emission can be reduced at the rate of $10 (cited by Kopp, 2011).

In an early study Moulton and Richards (1990) worked on costs of carbon sequestration through plantation and forest management in the United States. Using a very simple economic model (bottom-up-engineering) they estimated the cost of sequestration on land and planting costs though the carbon sequestration for hypothetical carbon sequestration program was calculated on available land and forest carbon accumulation rate. They found that the cost of carbon sequestration ranges from $5.26 to $43.33 per ton. They cautiously suggested that forestland and marginal pastureland are least costly opportunities for carbon sequestration. But sometimes carbon sequestration projects can increase the prices of the agricultural land and it can lead the land owners to convert part of unregulated forests to agriculture, which offsets some of the carbon sequestration.

Richards and Stokes (2004) critically reviewed several studies on carbon sequestration costs. They found that the cost of carbon sequestration ranges from $10 to $150 per ton of carbon sequestration. This cost is consistent a sequestration of 250 to 500 million tons in the USA and more than 2000 tons carbon globally. They reviewed that the cost of carbon sequestration varies across regions and within a region it varies across studies due to different methods of calculation.

Pfaff and Kerr (1999) and Pfaff et al. (2000) assessed the carbon sequestration and its cost function. They defined a carbon sequestration supply function or marginal cost of carbon sequestration in Costa Rica as a relationship between a monetary carbon reward and carbon sequestration supplied by the landowners. They used existing Global Information System (GIS) data on land use and land cover and other factors affecting the land use choices. They used three types of modeling such as advance process-based modeling which is known as CENTURY Model for simulation of Carbon (C) and Nitrogen (N) dynamics which reflects carbon to nitrogen activity in soil sample, advance empirically-based modeling for carbon storage where they used advance adaptation of life zone type modeling for predicting carbon storage and finally advance observationally-based economic modeling of land cover (GIS projection). In economic modeling, they considered the landowners to solve a dynamic optimization problem where the landowners seek to earn the greatest returns from the land uses. The return also depends on land characteristics, present and past land use, price and yields of different crops, cost of production and access to market, cost of changing land use, and expected future values of these factors. Depending on their theoretical model they derived empirical/econometric models which focused the effects of key observable factors in the estimation process. In estimation they used both the traditional approach and more dynamic approach.

Makundi and Okiting'ati (1995) estimated carbon emissions from Tanzanian forest sector, evaluated response options in the forestry sector with cost and benefit approach and discussed various options and barriers. By using the COPATH Model they showed that plantation in 1990 deforested area can provide 0.26 million ton of carbon if it is prompt uptake and 7.05 million ton in delayed uptake. For estimating cost, they used factor input obtained from Makundi (1979) and Swedeforest Consulting AB. In conservation option, they found that per ton of carbon costs $1.27 on average in different conservation forests while carbon from avoiding deforestation costs $1.06 to $ 3.4 per ton at 0% discount rate. At 10% discount rate they found the eucalyptus and maize option has the highest net present value with $1.73 per ton and government plantation gives negative net present value of $0.13 per ton of carbon sequestered. Finally, they argued that Tanzania has a cost effective GHG mitigation opportunities in the global level.

Masera et al. (1995) studied the economic response options to avoid carbon emission and increase carbon sequestration in the forests in Mexico. They examined the carbon sequestration and its cost in three policy scenario in the years 2000, 2010 and 2030. For these policy scenarios, they used benefit-cost analysis. They performed the study using available primary information on benefit, cost and other carbon related parameters. They observed the unit establishment cost in carbon sequestration is $0.3 to $14 per ton of carbon in all scenarios where yearly estimated carbon sequestration is 115 million ton. Calculating the benefit-cost analysis with 10% discount rate they found that option results in low net benefit equated $58 per hectare. In conclusion, they suggested that Mexican forest has potentials to carbon sequestration as it is profitable.

Ravindranath and Somashekhar (1995) studied India’s carbon emission from forestry sector, estimated the potentials for carbon sequestration and considered financial analysis of forestry option. For carbon sequestration under forestry option they considered maximizing Net Present Value (NPV) of economic benefit of per ton of carbon sequestration. For conducting this NPV approach, they stated that the investment cost in per ton of carbon sequestration for Natural Regeneration (NR) forest is $1.5, in Afforestation (AF) is $1.6 per ton of carbon, Enhanced Natural Regeneration (ENR) $2.5 per ton, Timber Forest $ 3.3 per ton of carbon, Community Woodlot (CW) $5.6 per ton and in Soft Wood Forestry (SWF) is $7.3 per ton of carbon. They also compared the forestry options with different energy options and found that the investment cost in per ton of carbon sequestration is very low in all forestry options.

Brown **(**1996) noted that unit cost of reducing carbon by decreasing deforestation through protecting forest tend to be lower and it ranges from $1 - $6 per ton of carbon in most tropical countries because of high carbon density (50-100 ton per hectare). She also mentioned that the cost of sequestration will be increasing if opportunity cost of using, planting and maintaining land is considered. In addition, she reported from recent studies that costs range in $2 - $20 per ton of carbon. She also mentioned the variation across different regions. For example in India per ton of carbon sequestration costs $3 - $9 and in Thailand it costs $13 - $26.

The opportunity of earnings from the carbon market in developing countries was discussed in a report by McDowell (2002). He argued that rural communities in the world's poorest nations will be able to earn income by using their forests and agricultural land to sequester carbon dioxide under a plan announced by the World Bank. The announcement will help bio-carbon fund to allow companies and public sector organizations in the developed world to offset some of their carbon emission in the projects in developing world, such as tree planting schemes which absorb carbon from the atmosphere.

The benefits that developing countries can derive from carbon sequestration were discussed in Niles et al**.** (2002). They pointed out that 47 tropical and sub-tropical developing countries have the potential to reduce carbon burden by about 2.3 billion tons of carbon in the next 10 years. Calculating carbon sequestration they used carbon uptake potential for non-commercial planting while the data they used for areas of land could be reforested with natural and assisted regeneration from secondary sources. Then the areas have been multiplied by the carbon accumulation rates ranging from 0.5 to 2.5 ton of carbon per hectare for dry tropical area and 2.5 to 5.0 per ton for humid tropical areas. These accumulation rates they used were collected from appropriate case studies and from country's general climatic profile. To avoid difficulties and likely monitoring verification, they used the lower end of the range for all countries in estimating carbon sequestration. For sustainable agriculture practice, they used Food and Agricultural Organization (FAO) statistical data on area and carbon potentials from secondary source of more than 200 agricultural projects. Finally for avoiding deforestation they multiplied the most recent deforestation rate by area weighted carbon stock. They have shown that a given price of $10 per ton of carbon and 3% discount rate will generate $16.8 billion earnings collectively for those countries.

Therefore, carbon sequestration and estimation of carbon sequestration cost function has much importance in the context of developing countries. There are many measures that can be used to estimate the carbon sequestration cost function or supply function. Irrespective of econometric model, a most used measure of estimating this supply function or cost curve is bottom-up engineering cost analyses or optimization model where marginal costs are constructed by the use of information of revenues and costs of production of alternative land uses on representative types or locations of land, and sorting these in ascending order of cost (Lubowski et al., 2006).

The reviewed literatures have provided opportunity to focus on carbon sequestration potentials, carbon accumulation rate in various options, carbon sequestration cost and benefit of carbon sequestration in different developing countries. The studies discussed in the literature review part have focused estimation of carbon sequestration cost either only one country or some regions of a country. None of the studies is found to estimate the carbon sequestration cost function in global perspective. This study has concentrated in estimating carbon sequestration cost function globally. On the other hand, some of the literatures proved that the carbon sequestration is less costly in some countries. So another goal of this study is to estimate and examine how cost effective it is. Unexpectedly none of the studies has focused on the responsiveness of carbon sequestration cost function which has a serious implication on the reduction of carbon emission in the ground. So this study has tackled the issue of the responsiveness of the carbon sequestration cost with respect to carbon sequestration. The future of emission reduction target through carbon sequestration depends on the cost of carbon sequestration. If the sequestration is less costly, then many countries will come ahead in carbon sequestration. As a result, estimating carbon sequestration cost function is more significant in combating climate change effects.

Chapter-3: Theoretical Background

Let us consider the total land supply A_0, which the land owner can use in conventional agriculture or in carbon sequestration. It is assumed that every land owner is profit motivated. So, given the available land, they will decide how much land to use in conventional agriculture and for carbon sequestration while the total supply of land is fixed. Then, the objective function of a firm or land owner is to maximize the following profit function (Π) subject to total supply of available land (A_0).

Max $\prod = P^Q Q(A^Q) + P^S S(A^S) - C^Q(A^Q) - C^S(A^S)$ (1)

Subject to $A^Q + A^S \leq A_0$ (2)

Here $\prod$ = Profit of a land owner, Q = Quantity of output from agricultural or any other land used sectors, S = Total quantity of sequestered carbon, P^Q = Price of agricultural output, P^S = Price of carbon, A^Q = Land uses in agricultural sector, A^S = Land uses in carbon sequestration sector, C^Q = Cost of land uses for output production, C^S = Cost of land uses for carbon sequestration.

For profit maximization, marginal net returns of land use in both sectors (agriculture and carbon sequestration) need to be equal, which is necessary condition i.e. First Order Condition (FOC) derived from the Lagrangian,

Max $L = P^Q Q(A^Q) + P^S S(A^S) - C^Q(A^Q) - C^S(A^S) + \lambda\left[A_0 - A^Q - A^S\right]$ (3)

$\{A^Q, A^S)$

Here L = Lagrangian profit function, λ = Lagrangian multiplier; shadow price/ cost of land uses. So, the FOCs for profit maximization are,

$$\frac{\partial L}{\partial A^Q} = P^Q \frac{\partial}{\partial A^Q} Q(A^Q) - \frac{\partial}{\partial A^Q} C^Q(A^Q) - \lambda = 0 \quad (4)$$

$$\frac{\partial L}{\partial A^S} = P^S \frac{\partial}{\partial A^S} Q(A^S) - \frac{\partial}{\partial A^S} C^S(A^S) - \lambda = 0 \quad (5)$$

$$\frac{\partial \lambda}{\partial A^Q} = A_0 - A^Q - A^S \quad (6)$$

From equation 4 and 5 we get,

$$\lambda = P^Q \frac{\partial}{\partial A^Q} Q(A^Q) - \frac{\partial}{\partial A^Q} C^Q(A^Q) = P^S \frac{\partial}{\partial A^S} Q(A^S) - \frac{\partial}{\partial A^S} C^S(A^S) \quad (7)$$

$$\lambda = \Pi_{A^Q} = \Pi_{A^S} \quad (8)$$

Here $\Pi_{A^Q} = \frac{\partial \Pi}{\partial A_q}$ refers marginal return of land used in agriculture sector and $\Pi_{A^S} = \frac{\partial \Pi}{\partial A_s}$ refers marginal return of land used in carbon sequestration sector. That is any firm or landowner will allocate his/her land use in agriculture and in carbon sequestration project in such a way that the marginal net return/profit is equal to λ in both sectors. This condition is illustrated in Figure 1.

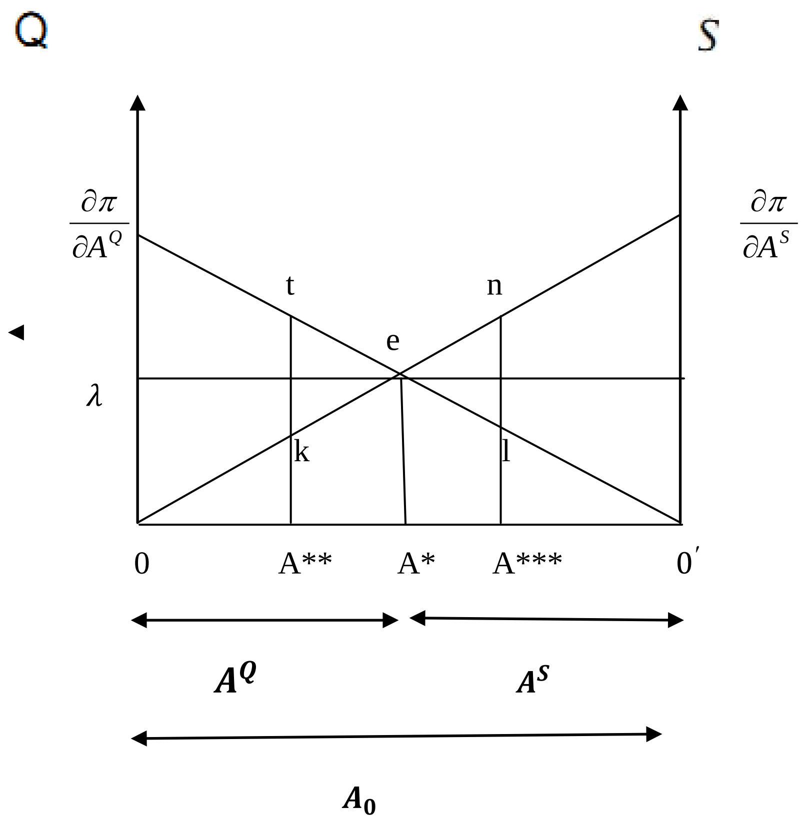


Figure 1: Optimal Allocation of Land Use

Optimal condition for land use: $\frac{\partial \Pi}{\partial A^Q} = \frac{\partial \Pi}{\partial A^S} = \lambda$

The optimal allocation for land use became very important after the world faces the incremental pressure of population increase. Generally speaking increased population needs food and energy which indeed requires changes in the systematic use of land and ultimately leads to pressure on land use. In contrast, to mitigate global climate change affects the concern of limiting carbon emission demand has intended to increase the demand for land use for carbon sequestration projects. In these circumstances, change of a cultivable land to forest land for carbon sequestration would be optimal if the following condition holds; $\frac{\partial \pi}{\partial A^Q} = \frac{\partial \lambda \pi}{\partial A^s} = \lambda$ which is the optimal condition for land use.

In the above Figure 1, A* is the optimal allocation of land where 0A* units of land (=A^Q) is allocated for conventional agricultural sector and $0'A*$ units of land ($= A^S$) is allocated for carbon sequestration with equal net marginal benefit which is in turn equal to shadow price (=λ). If land use increases in favor of conventional agriculture, say for example 0A* to 0A***, then the marginal benefit from agricultural sector will increase by area $A*elA***$. On the other hand land use reduction in carbon sequestration sector will decrease the marginal benefit by about the area $A*enA***$. As a result, the land owner or the farm will be worse off by the area enl which a social loss. Thus a profit motivated investor or land owner will allocate the land use in such a way that the marginal benefits from both sectors are equal to each other. The same result may happen if the land use increases in favor of carbon sequestration. In that case, the land owner will experience a loss of marginal benefit from agriculture sector amounting to the area etk . So, carbon sequestration will be enhanced if the marginal net benefit of land use in carbon sequestration is larger than marginal net benefit of land use in agriculture sector. The cost of carbon sequestration is thus the net forgone profits from agriculture and increased marginal profits from carbon sequestration.

In order to estimate supply or demand function for carbon sequestration we need data on price of carbon sequestration either from demand side or from supply side and data on prices of agricultural output. Unfortunately, in the data section we did not find data on carbon prices as carbon sequestration is a new phenomenon in the global economy. In this regard, this study concentrates on estimating the carbon sequestration cost function for developing countries assuming that the cost function is based on profit maximizing behaviors presented in this section. That is, the carbon sequestration costs will not be undertaken unless they cover opportunity cost of the land. Therefore, we have ignored the cost for producing conventional agricultural products. The focus of this study is only on carbon sequestration cost (responsiveness) function for developing countries

Chapter-4: Determinants of the Cost of Land Use for Carbon Sequestration

The cost of carbon sequestration mainly depends on the opportunity cost of land, costs of maintenance, transaction and plantation. Forest Carbon Index (FCI, 2009) has concluded that except the opportunity cost of land the other costs are negligible and it considered other costs in transaction cost (growing and protecting a forest, human labor cost and machinery) which is estimated only 13 % of the project cost.

In addition, the cost function has some exogenous determinants like Clean Development Mechanism (CDM) projects and Per-Capita GDP (in PPP). If there is a CDM project in a country it will affect the cost of carbon sequestration. Furthermore, if the per capita GDP increases in a country it means that more land is used in favor of other sectors. In that case land use in favor of carbon sequestration will be more costly. In all the cases the costs exceed the benefit of land use for carbon sequestration which is shown in Figure 1.

The carbon sequestration cost function depends on land use changes like afforestation/reforestation, sustainable agricultural practice, deforestation halted and size of forest area. Thus, the change of these affects the carbon sequestration through changing land use and thus the cost of carbon sequestration. If any changes of these determinants increase the quantity of sequestrated carbon, it will increase the cost (shown above in Figure 1, reducing the benefit of other cultivation). These variables work as instrument in the carbon sequestration which in turn affects the cost function.

The more the afforestation/reforestation takes place, the more land is distributed in favor of carbon sequestration increasing the opportunity cost of land. The tropical countries are feasible for afforestation (Rokityanskiy et al, 2007) which is better than the mature forest in terms of carbon sequestration as plantation accumulates higher rate of carbon sequestration (Bloomfield and Pearson, 2000). If the reforestation rate increases it will increase the cost of sequestration. On average 33-44% of the reduction (carbon reduction) could be met cost effectively through forest-based sequestration (Sedjo et. al., 2001).

Deforestation is considered as the second largest source of anthropogenic carbon dioxide emission after fossil fuel and the estimates is about 12% of global emission (Werf et al. 2010).

Reduction of deforestation and degraded forests is an important source of carbon emission reduction by increasing sequestration. Avoiding deforestation has some other indirect benefits like bio-diversity, water and air quality and maintenance of local climate (Bloomfield and Pearson, 2000). The USEIA emphasized it as cost effective measure as deforestation is responsible for 18-25% of global GHG emission (Kopp, 2011). In order to avoid deforestation land owner needs to be compensated as they have the opportunity to produce other commodity in their land which also increase the cost of carbon sequestration. Presently, many private organizations like NGOs have started carbon sequestration projects like Reducing Emission from Deforestation and Degradation (REDD) in some developing countries. REDD project is a market based (generate tradable carbon permit) and fund based (developing countries receive cash payments) incentive payments to the developing countries for promoting not to do deforestation and degradation. Private companies, NGOs and national governments are taking REDD project in different developing countries for carbon sequestration through reducing deforestation (Ecomagazine, 2012, web). So, reducing deforestation is a key determinant of carbon sequestration through changing land which in turn affects the cost of carbon sequestration.

Conventional agriculture system is claimed to be an important source of carbon emission. Small firm size and use of pumps in agricultural sector are mainly responsible for carbon dioxide emission which is very common in Sub-Saharan African countries using pumps for irrigation emitting carbon. But energy efficient small scale pumps can reduce farmers running costs and keep carbon dioxide emission at low rate (Sugden, 2010). In Ireland agriculture represents 29.1% of total national GHG emissions. National emission reduction target by 2020 in the 'Climate Change Response Bill' emphasizes 30% emission reduction in agricultural sector so that the indigenous industry (agriculture) has the sustainable development (Schulte and Lanigan, 2011). So, sustainable agricultural practice is an indicator of land use which can affect the carbon sequestration in the developing countries. This agricultural system is defined as a management system for renewable natural resources that provides food, income, and livelihood for present and future generations, and which ultimately will maintain/improve the economic productivity and ecosystem services of these resources (Blumentha, 2012, web). In all the developing countries and (or) underdeveloped countries agriculture is an important sector because of their dependence on agriculture for supplying food for the huge population. As a result, unmanaged and unplanned agricultural practice is continuing with social and ritual tradition. Though some times the sustainable agriculture comes as contradictory with the values of the farmers but it is increasing for the last few years (Blumentha, 2012, web). New farming system like agro-forestry, alley and multiple cropping could be the good practice of sustainable agriculture and it is more profitable and environmental friendly than traditional agriculture. Agro-forestry is found more profitable than shifting cultivation (a traditional cultivation in the hilly areas) while shifting cultivation is responsible for carbon emission. It needs new land to prepare in rotation basis by firing the hilly forest lands to convert in cultivable land for food production (Hossain et al., 2006). Conversely, sustainable agriculture practice can help in reduction of forest land conversion into cultivable land using the existing agricultural land effectively and pasture along with reduction of greenhouse gas emission (Bloomfield and Pearson, 1999). Thus, the opportunities arise for increasing carbon sequestration on sustainable land use in agricultural sector.

Forest area is another important determinant of carbon sequestration. If the size of a forest increases it will increase carbon sequestration. Sedjo and Solomon (1998) emphasized expanding forest areas to offset world's carbon sequestration (cited from Richards and Stokes, 2004). As forest is considered as the sink of carbon sequestration thus it is expected that the area of forest is proportionately related to the carbon sequestration. That is the more the sink increases the more the sequestration increases.

Clean Development Mechanism (CDM) is the flexible mechanism under the Kyoto Protocol by which the Annex I countries are funding projects in the developing countries for carbon sequestration. The presence of a CDM project in a country will affect the cost function as an exogenous variable as it needs land distribution in favor of the project reducing the other cultivation sectors. In many developing countries CDM projects are working on commercial basis for supplying carbon credits to the developed countries. At present, almost 7912 active CDM projects are in the pipeline in different countries. Among the CDM projects, top 20 buyer companies are funding 2665 projects in the different part of the globe (UNEP Riso Centre, 2012). According to UNFCCC, *"CDM allows emission reduction projects in developing countries to earn certified emission reduction (CER) credit, each equivalent to one ton of* CO_2*. These CERs can be traded or sold and be used by industrialized countries to meet a part of their emission reduction targets under Kyoto Protocol"* (UNFCCC, 2012, web). As CDM projects are initiated for carbon sequestration in the developing countries by the industrialized developed countries, the presence of a CDM projects in a developing country means that it uses land for project which will increase the cost of carbon sequestration.

Per Capita GDP (in PPP) is the indicator of economic growth and development and hence an indicator of carbon dioxide emission by Kaya Identity (1990) which is an equation that determines the carbon dioxide emission by population or by a country. This formula calculates the carbon dioxide emission as a product of population, per capita GDP, energy use of per unit of GDP and carbon emission in per unit of energy consumed (The Dictionary of Sustainable Management, 2012). Thus Per Capita GDP is an exogenous variable in carbon sequestration cost function. Economic growth and emission are positively related. Higher economic growth relates to higher emission and lower economic growth relates to the lower emission. But lower emission also indicates emission reduction as well. Most of the developing countries are agro-based and less industrialized. As a result, accelerating higher Per Capita GDP means higher production, more emission and more use of land in other cultivation sectors rather than carbon sequestration. As per capita GDP increases the opportunity cost of land use will increase in carbon sequestration, which affects the cost function. So, if the per capita GDP increases in the developing countries, it will increase the cost of carbon sequestration and thereby leading to less sequestration.

Now the discussion above indicates the selection of the independent variables for the carbon sequestration cost function. Total Cost (TC) of carbon sequestration is the dependent variable. The independent variables are Carbon Sequestration Supply (CSS), presence of Clean Development Mechanism (CDM) projects, GDP (in PPP). In addition the CSS function also depends on some land use behavior like Deforestation Halts (DH), Afforestation/Reforestation (AF/RF), Sustainable Agricultural Practice (SAP) and Forest Area (FA) respectively.

Chapter-5: Data Sources and Analysis

The data used in this study is obtained from secondary sources. Considering the availability of data, my sample contains 58 developing countries (Appendix A). The data for different variables are collected from different sources like Niles et al., (2002), FAO, UN Data, CDM Pipeline, World Bank and some published journals. Details can be consulted in Table 1.

Table 1: Variables and Data Sources

Name of Variable	Data Source	Variable Type
Total Cost (million USD)	Deveny et al., (Forest Carbon Index 2009)	Dependent
Carbon Sequestration (million ton)	Niles et al., (2002) Deveny et al., (Forest Carbon Index 2009)	Independent
Afforestation/ Reforestation Rate (1000 ha)	Niles et al., (2002) & FAO Forest Data	Independent
Deforestation Halts (1000 ha)	Niles et al., (2002)	Independent
Sustainable Agriculture Practice (1000 ha)	Niles et al., (2002)	Independent
Forest Area (1000 ha)	UN data (2007)	Independent
CDM (1=yes, 0= otherwise)	CDM Pipeline, UNEP Riso Centre	Independent
Per capita GDP, PPP (Current International Dollar)	World Bank's Data Bank	Independent

Note: Data compiled from different sources.

Total cost of carbon is simply calculated by multiplying the Average Unit Cost (AUC) of carbon by Sequestered Quantity of Carbon (S) i.e. TC = AUC*S. Average unit cost is presented in USD per ton carbon in Forest Carbon Index (FCI), 2009 (Deveny et al. 2009). FCI (2009) has calculated the cost for one ton of carbon sequestration in different developing countries. For calculating the cost it considered the opportunity cost of land that is total forgone future revenue of agriculture and timber. With different discount rate in different regions of the world they calculated the opportunity cost for next 100 years. For this thesis, the average unit cost is chosen from their cost calculation which is then used to find total cost of carbon sequestration. Missing average unit cost for some countries were calculated taking the average or equivalent to the neighboring countries (Appendix B).

Carbon Sequestration data is collected from Niles et al. (2002). The estimates of carbon sequestration from different land uses are then added to get the total sequestration (from reforestation, deforestation halted and sustainable agriculture practice) where they have estimated the carbon sequestration for each activities separately. The data was accounted for a period of 2003-2012 in million tons of carbon. In their work Niles et al., (2002) considered only 47 countries but here I considered 58 countries using their original data sheet. The missing data for eight countries (Appendix C) out of eleven more countries I used in my sample were collected from Devney et al. (FCI, 2009) as proxy and remaining three countries data from the original data sheet of Niles et al., (2002).

Reforestation/afforestation rate is jointly collected from Niles et al. (2002) and FAO forest data. Niles et al. (2002) is the main source of this data and the missing data for some countries (Appendix C) were collected from FAO data. In FAO data for some countries afforestation and reforestation data is jointly used as in some countries reforestation was not available and thus the term afforestation and reforestation is used interchangeably. This data is used 1000 ha per year in a country.

Deforestation halted data is also expressed in 1000 ha per year which is used from Niles et al. (2002). Deforestation halted means how much deforestation is reducing in a country in a year.

In addition sustainable agricultural practice expressed in million ha per year is also collected from Niles et al. (2002). The rate of sustainable practice means how much area is under sustainable agricultural practice in a country in a year.

Forest area data is collected from UN data (2007) which is expressed in 1000 ha.

The CDM project data is collected from CDM Pipelines under UNEP Riso Centre (March, 2012). Finally the Per Capita GDP, PPP is used from World Bank (2005) data. This data is expressed in current international dollar. The current international dollar also known as

Geary-Khamis dollar that is widely used in economics which is a hypothetical dollar having same purchasing power like the US dollar in USA (UNSTATS, 2012).

After collecting the data, mathematical and graphical diagnosis were conducted to check whether the data satisfy the normality assumption. Normality is the most important characteristics of the raw data. A normally distributed observation is bell-shaped and well behaved which distributes the data equally in both sides of the median value.

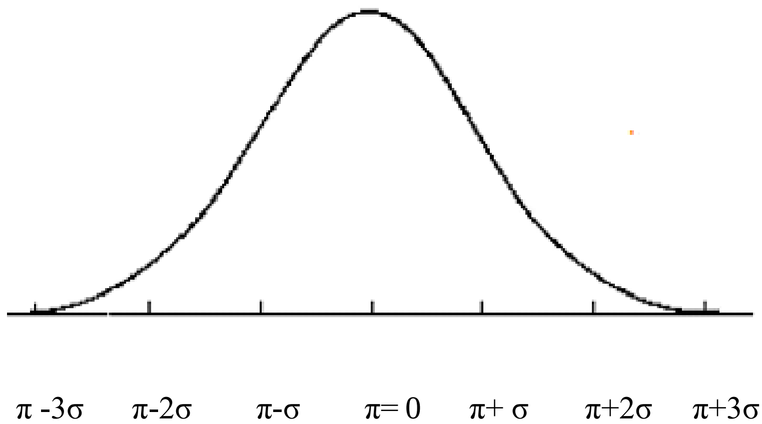


Figure 2: Standard Normal Distribution Curve (π=0, σ=1)

In a normally distributed distribution mean, median and mode all are equal. In most of the cases 68% observations are clustered between -1σ to +1σ, 95% observation exists between -2σ to +2σ and 99.7% observation lies between -3σ to +3σ in the normally distributed data. Thus normality assumption is an important characteristic of a data set. To find the trend the study has tested the data set with the help of Eviews 7 and found the following descriptive statistics, which show that none of them are normally distributed. Thus the data set is not satisfying the normality assumption.

Table 2: Descriptive Statistics of Data

Name of Variables	Mean	Median	St. Deviation	Skewness	Kurtosis	Jarqe-Bera	Probability
Total Cost (M USD)	664.54	222.60	1557.50	6.07	42.72	4169.13	0.00
CSS (MtCO2)	47.50	18.01	102.67	5.72	39.23	3488.83	0.00
CDM (1=yes, 0= Otherwise)	0.74	1.00	0.44	-1.10	2.22	13.24	0.00
Per Capita GDP (Int. dollar)	3726.33	2153.03	3520.42	1.17	3.06	13.24	0.00
Afforestation/ Reforestation (1000ha)	65.77	20.00	128.86	3.65	17.38	628.00	0.00
Deforestation Halted (1000 ha)	29.84	10.15	62.68	4.18	21.81	1023.98	0.00
Sustainable Agriculture (1000ha)	903.55	450.00	1713.94	4.41	25.27	1386.97	0.00
Forest Area (1000 ha)	31338.00	12067.00	68302.00	5.07	31.65	2232.00	0.00

Note: The data statistics were calculated with the help of Eviews 7

Thus we need to take the remedial measures so that the data comes at least close to the normal distribution. A widely used transformation method for non-normally distributed data is Box-Cox transformation. By the Box-Cox transformation to transform a variable Y to Y" a parameter λ is used while $T(Y) = \frac{T^{\lambda}-1}{\lambda}$ where λ can take any value between -5 to +5. But a standard region is -1 to +1. In contrast λ=0 is simply the natural logarithmic transformation and λ=1 is linear transformation. Here, to transform the non-normally distributed data we used natural logarithmic transformation for all variables except the binary variable Clean Development Mechanisms (CDM). Moreover, variables taking 0 (zero) values were considered a minimum positive value (0.0001) to avoid mathematical errors in logarithmic transformation. After transformation, the data look like normally distributed though they are not exactly normal.

Table 3: Descriptive Statistics after Data Transformation

Name of Variables	Mean	Median	St. Deviation	Skewness	Kurtosis	Jarqe-Bera	Probability
$LnTC$	5.39	5.40	1.53	0.00	2.38	0.93	0.63
$LnCSS$	2.83	2.89	1.49	0.01	2.39	0.90	0.64
CDM	0.74	1.00	0.44	-1.10	2.22	13.24	0.00
$LnGDP(PPP)$	7.78	7.67	0.98	0.04	2.14	1.78	0.41
$LnAF/RF$	2.89	2.99	1.77	-0.15	2.43	0.98	0.61
$LnDH$	2.16	2.31	1.73	-0.44	3.44	2.38	0.30
$LnSAP$	5.88	6.10	1.49	-0.84	5.87	26.83	0.00
$LnFA$	9.28	9.40	1.59	-0.63	4.46	8.98	0.01

Note: $LnTC$ = Natural log of Total Cost, $LnCSS$ = Natural log of Carbon Sequestration, CDM = Clean Development Mechanism (1 = There exists at least one project in the country and 0= others), $LnGDP(PPP)$ = Natural log of per capita gross domestic product in international dollar in terms of purchasing power parity, $LnAF/RF$ = Natural log of afforestation/reforestation, $LnDH$ = Natural log of deforestation halted, $LnSAP$ = Natural log of sustainable agricultural practice and $LnFA$ = Natural log of forest area.

The above table shows that mean and median are very closer to each other and the skewness is close to zero meaning that the transformed data follows the normally distributed variable (not exact normal). It is also seen that variables $LnSAP$ (log of sustainable agricultural practice) and $LnFA$ (log of forest area) are not that much close to normally distributed variable. It could be the reason of small sample size.

Chapter-6: Econometric Models and Results

Since carbon sequestration is a dependent variable of land use characteristics I have chosen the Instrumental Variable (IV) regression to estimate the cost function. In IV estimation of cost function carbon sequestration is considered as endogenous variable which is correlated with land use change variables. The instrumental variable was first introduced by Reiersøl, considering exact relationships in economic variables are affected by random disturbance or measurement errors (Sargan, 1958). This estimate is used when some variables are assumed to be omitted or excluded from the models which are correlated with the explanatory variables but unobservable. Thus it is used to obtain a consistent estimator of unknown coefficients of the population parameters when regressor X is correlated with the error term u (Stock and Watson, 2006). It is also used in case of simultaneous causality bias (where explanatory variable causes dependent variable and dependent variable causes explanatory variable) and errors in variables (Aldrich, 1993 and Gujarati, 2004). In this study, land use characteristics are not included in the carbon sequestration cost function which is to be estimated. That is some land uses characteristics (afforestation/reforestation, sustainable agricultural practice and deforestation halted) are excluded from the cost function though these variables have impact on cost function through the endogenous variable carbon sequestration. These variables are considered as excluded exogenous variables. This means that the exclusion principle of instrumental variable exists in the carbon sequestration cost function as the endogenous variable carbon sequestration (CSS) is functionally related to those omitted or excluded land use variables. In addition, it is assumed that there might be some measurement errors in the variables because those were collected from different sources. Thus, this study is conducted using the instrumental variable approach (IV regression). The properties of any instrumental variables are as follows,

The instruments; Zi are exogenous that is Cov (Zi, ε) = 0 but the Cov (X, Zi)$\neq$ 0, that is they are correlated. Here Zi's are ith instruments (i =1, 2, 3-----n), ε is error term and X is the endogenous variable in the model. If these two conditions hold then the instruments are considered as valid.

The econometric model of the cost function is then written as,

$$lnTC = \alpha_1 + \alpha_2 \, lnCSS + \alpha_3 CDM + \alpha_4 lnGDP + \varepsilon \quad (9)$$

While the LnCSS is a function of several instrumental variables and thus LnCSS can be expressed as,

$$lnCSS = \mu_1 + \mu_2\ lnDH + \mu_3\ lnRF + \mu_4\ lnSAP + \mu_5 lnFA + \theta \qquad (10)$$

Here ε and θ are error terms, α_1 (in eq. 9) and μ_1 (in equation 10) are intercepts. The coefficients are α_2, α_3 and α_4 (in equation 9) and μ_2, μ_3, μ_4 and μ_5 (in equation 10) to be estimated.

Now using STATA 11 we can estimate equation (9) and (10). As the LnCSS is the function of instrumental variables (excluded exogenous variables), we can estimate the total cost function considering the instrumental variables. Here, we can instrument the variable LnCSS and estimate LnTC (equation 9) directly with a single equation model. While estimating equation (9) and (10) we use different models with variability of variables. There are two alternative models we have used for regression part. In each alternative equation, estimations are done with a variation in included exogenous variable. The only difference in two models is inclusion of Clean Development Mechanisms (CDM). In first case it is considered as excluded exogenous variable (equation 11) and in second case it is considered as included exogenous variable (equation 12). These models are given below.

Model 1: $lnTC = \alpha_1 + \alpha_2\ lnCSS + \alpha_3\ lnGDP;\ ln\ CSS = \mu_1 + \mu_2\ lnDH + \mu_3\ lnRF + \mu_4\ lnSAP + \mu_5 CDM + \mu_6\ lnFA$ (11)

Model 2: $lnTC = \alpha_1 + \alpha_2\ lnCSS + \alpha_3 CDM + \alpha_4 lnGDP;\ ln\ CSS = \mu_1 + \mu_2\ lnDH + \mu_3\ lnRF + \mu_4\ lnSAP + \mu_5\ lnFA$ (12)

Another model 3 is a simple Ordinary Least Square (OLS) model which will be estimated to compare with the other models, which is written as

Model 3: $lnTC = \alpha_1 + \alpha_2 lnCSS + \alpha_3 lnDH + \alpha_4\ lnRF + \alpha_5 lnSAP + \alpha_6 CDM + \alpha_7 lnGDP + \alpha_8\ lnFA + \varepsilon$ (13)

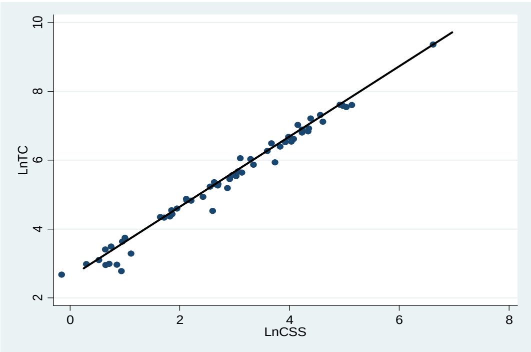
Table 4: Estimated Results

Variables	Model 1	Model 2	Model 3
Constant	2.133 (0.273) (7.80)	2.107 (0.282) (7.46)	2.251 (0.362) (6.22)
LnCSS	0.997* (0.036) (27.38)	0.983* (0.044) (22.12)	1.017* (0.030) (33.76)
LnDH			-0.009 (0.007) (-1.26)
LnAF / *RF*			0.0003 (0.009) (0.04)
LnSAP			-0.358** 0.0204 (-1.75)
CDM		0.053 (0.080) (0.66)	0.133 0.0812 (0.16)
LnFA			0.05388 (0.0377) (1.43)
$LnGDP_{ppp}$	0.057 (0.042) (1.37)	0.061 (0.043) (1.40)	0.007 (0.031) (0.23)
R^2	0.9822	0.9820	0.9834
$Adj\ R^2$	0.9821	0.9814	0.9811
F df $P\rangle F_{value}$	853.38 (2, 55) (0.00)	528.89 (3, 54) (0.00)	433.00 (7, 50) (0.00)

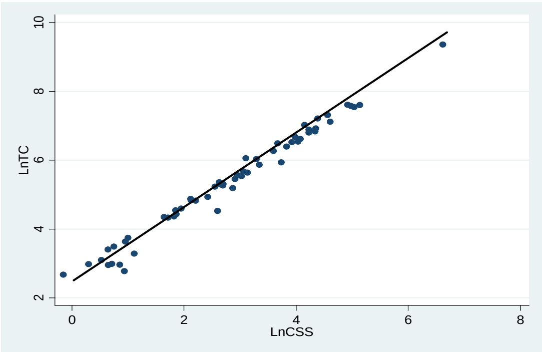
Note: The parentheses show the robust standard errors and t/z statistics (shaded one).
* means 5% and ** means 10% level of significance of coefficients.

Table 4 shows the estimated results of the different models of the cost function. In model 1 and 2, we have used combined/one command of instrumental variable regression approach. In model 1, Clean Development Mechanisms (CDM) is used as an instrumental variable of Ln of carbon sequestration (LnCSS) and thus it is not considered as excluded exogenous variable of Ln of total cost (LnTC). But in estimating model 2, Clean Development Mechanisms (CDM) is considered as an included exogenous variable of ditermining the Ln of total cost (LnTC). After regressing these two models (model 1 and model 2) the coefficients of Ln of carbon sequestration supply (LnCSS) are found statistically significant at 5% level. But the coefficient of Clean Development Mechanisms (CDM) and Ln of GDP (LnGDP) are not statistically significant at 5% and 10% level in both models. In both models the value of R^2 is 0.98 with significant F statistics. The adjusted R^2's are also close to the unadjusted R^2's shown in Table 4. Though the high R^2 value shows the goodness of fit of the models but few insignificant t statistics mean that there could be the presence of multicollinearity in these two models.

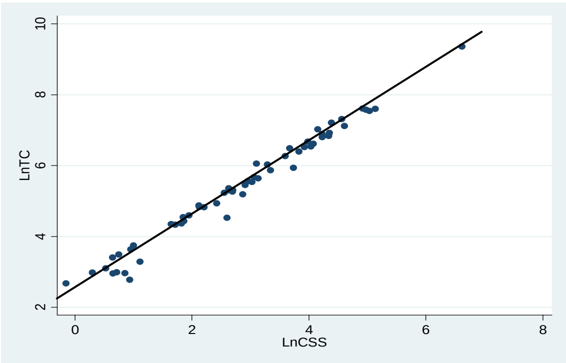
Model 3 shows that the coefficient of Ln of carbon sequestration (LnCSS) is significant at 5% level of significance and the coefficient of Ln of sustainable agricultural practice (LnSAP) is significant at 10% level of significance and no other variables are significant at any level though the coefficient of determination; R^2 is sufficiently high (about 98%). It means the model has multicollinearity problem with high R^2 and insignificant t ratios. The coefficients in the different models are the partial elasticity of different variables. The following graphs show the percentage change in total cost due to the percentage change in carbon sequestration (cost elasticity of carbon sequestration) in three different models estimated in this study. The graphs show that the cost elasticity of carbon sequestration is close to unitary in all models.



Model 1: LnTC on LnCSS



Model 2: LnTC on LnCSS



Model 3: LnTC on LnCSS

Graph 1: Cost Elasticity of Carbon Sequestration

6.1: Multicollinearity Test

Multicollinearity among the explanatory variables is a common problem in the multiple regression analysis and it is alarming if there exists a linear collinearity among the variables. Multicollinearity means that the explanatory reggressors have collinearity to each other and as a result the coefficients become biased (either over estimated or under estimated from the actual values). In case of models 1, 2 and 3, results show that R^2 is very high but there are few insignificant t-statistics. That is there might be multicollinearity in these models. Thus to avoide multicollinearity we need to check whether there is multicollinearity among the explanatory regressors or not. One of the most popular methods to detect multicollinearity is auxiliary regression. In auxilliary regression, one of the explanatory variables is regreesed on other explanatory variables and then compared the R^2 of the auxiliary regression with R^2 of the main regression model. Multicollinearity will be a problem if the R^2 of the auxiliary regression is high. Here we have checked the multicollinearity problem in model 2 only as the R^2 in both models are equal that means the variable Clean Development Mechanisms (CDM) might be an irrelevant variable in model 2. But the inclusion of an irrelevant variable may be responsible for multicollinearity, thus it is necessary to test the multicollinearity for model 2. So, the auxiliary regressions for model 2 are as follows,

$$LnCSS = \lambda 1 + \lambda 2\ CDM + \lambda 3\ lnGDP \quad (14)$$

Table 5: Estimated Result of Auxiliary Regression of LnCSS

Constant	*CDM*	***LnGDP***	R^2	$AdjR^2$
-2.51	0.91 (0.4) (2.29)	0.60 (0.18) (3.33)	0.2830	0.267

Note: Parenthesizes are standard deviation and t statistics (shaded)

$$CDM = \lambda 1 + \lambda 2\ lnCSS + \lambda 3\ lnGDP \quad (15)$$

Table 6: Estimated Result of Auxiliary Regression of CDM

Constant	***lnCSS***	***lnGDP***	R^2	$AdjR^2$
-2.51	0.095 (0.041) (2.29)	0.05 (0.06) (0.79)	0.1448	0.1179

Note: Parenthesizes are standard deviation and t statistics (shaded)

$$LnGDP = \lambda 1 + \lambda 2\ CDM + \lambda 3\ lnCSS \quad (16)$$

Table 7: Estimated Result of Auxiliary Regression of LnGDP

Constant	*LnCSS*	*CDM*	R^2	$AdjR^2$
-2.51	0.279 (0.084) (3.33)	.223 (0.283) (0.79)	0.2235	0.1952

Note: Parenthesizes are standard deviation and t statistics (shaded)

The $R^{2\prime}$ and Adj $R^{2\prime}$of the auxiliary regressions (Equation 14, 15 and 16) shown in the above tables are very low compared with the $R^{2\prime}$ and Adj $R^{2\prime}$ of estimated model 2. This means that these models are not a good fit and thus there is no multicollinearity problem in model 2 (Equation 12). To be sure we can check by another method Variance Inflation Factor (VIF) in the following.

6.2: Variance Inflation Factor (VIF)

Variance Inflation Factor is another widely used method of detecting multicollinearity problem. Another method tolerance (Tol) level the inverse of variance inflation factor (VIF) is also used alternatively for detecting multicollinearity. When there is a perfect collinearity among the regressors the value of tolerance is zero (0) and if there is no collinearity among the regressors the value of tolerance is one (1). If there is higher multicollinearity problem in the model the value of variance inflation factor becomes larger and it is smaller if there is no strong multicollinearity problem. The relation of variance inflation factor (VIF) and tolerance (Tol) can be used as interchangeably (Gujarati, 2004) as tolerance (Tol) is equal to $\frac{1}{VIF}$. The resuts for variance inflation factor and tolerance are as follows.

Table 8: Variance Inflation Factor for Model 1

Variables	*VIF*	$Tol = \frac{1}{VIF}$
LnCSS	1.27	0.785273
LnGDP	1.27	0.785273

Note: VIF = Variance Inflation Factor, Tol = Tolerance

Table 9: Variance Inflation Factor for Model 2

Variables	*VIF*	$Tol = \frac{1}{VIF}$
LnCSS	1.39	0.716984
CDM	1.17	0.851590
LnGDP	1.29	0.776529

Note: VIF = Variance Inflation Factor, Tol = Tolerance

Table 10: Variance Inflation Factor for Model 3

Variables	*VIF*	$Tol = \frac{1}{VIF}$
LnCSS	2.02	0.495360
LnDH	1.35	0.740219
LnAF / RF	1.49	0.669881
LnSAP	1.24	0.808699
CDM	1.30	0.771293
LnGDP	1.42	0.705834
LnFA	1.81	0.553915

Note: VIF = Variance Inflation Factor, Tol = Tolerance

Here table 8 and table 9 show that the value of tolerance is less than 1 but not zero. Though the tolerance values are less than 1, they are seem to be larger and closer to one. That means there is no strong correlation among the regressors. So, none of the models are biased with multicollinearity problem and hence there is no strong multicollinearity in model 1 and model 2. On the other hand, table 10 (model 3) shows that the value of variance inflation factor for Ln of carbon sequestration (LnCSS), Ln of forest area (LnFA) and Ln of afforestation/reforestation are comparatively high (tolerance value is low). The VIF value for Ln of carbon sequestration is 2.02 means that the variance of this variable is more than twice of the actual variance. By the same way the variance of Ln of forest is also inflated by 1.81 times and variance of Ln of afforestation/reforestation is inflated by 1.49 times of the actual ones. These variables are biased with multicollinearity. Except this for model 3, both method of detecting multicollinearity; auxiliary regression and variance inflation factor (VIF) give the same result of having no exact multicollinearity problem in model 1 and model 2. In this situation the insignificant t statistics with high R^2 could be the reason of small sample size as multicollinearity is treated as a problem of sample (Gujarati, 2004).

6.3: Heteroskedasticity Test

Homoskedasticity (constant variance) implies that the variance of error term is constant. If this assumption does not hold then there arises heteroskedasticity. As a result, the variance is no longer minimum. In the instrumental variable (IV) regression the error may increase as instrumental variable increases. To avoid the heteroskedasticity, we have used the robust standard error while regressing the equations. Irrespective of robust standard error, there are several approaches to test the heteroskedasticity. One important approach is to plot the fitted values against residuals and observe whether there is any systematic pattern. Another most widely used procedure is White's General Test for heteroskedasticity. Model 1 and 2 are instrumented model and thus we have used robust standard error during the regression which are adjusted with the heteroskedasticity. Thus there is no heteroskedasticity in model 1 and 2. But for model 3, we checked the heteroskedasticity with White's General Test. The test procedure for model 3 is as follows:

White's test for Ho: homoskedasticity against Ha: unrestricted heteroskedasticity.

Table 11: Test of Heteroskedasticity for Model 3

Chi^2	$P(\Pr ob\rangle Chi^{2})$	df
27.28	0.7864	34

Note: P = Probability, df = Degrees of freedom

The White's homoskedasticity test for model 3 shows (Table 11) that there is heteroskedasticity in model 3. As a result, the standard errors are not homogeneous and thus model 3 violates the properties of Ordinary Least Square (OLS) estimators. Thus the coefficients in model 3 are not good estimators of the population parameter of the carbon sequestration cost function.

6.4: Endogeneity and Over Identification Test

Model 1 and 2 are regressed with single command IV regression and thus these two models need to satisfy the conditions of IV regression; endogeneity and over identification restriction. The tests are conducted as follows:

The model identification is an important condition for the instrumental variable regression. A model is said to be exactly identified if the number of instruments is equal to the number of endogenous variable, over identified if number of instruments is higher than the number of endogenous variables and under identified if the number of instruments is less than the number of endogenous variables. The assumptions can be tested if the model is over identified. The most common test for over identification restriction is Sargan test which consider that the residuals should be uncorrelated with the exogenous variables if the instruments are really exogenous. The Sargan (1958) test follows the chi-sq distribution which is calculated as NR^2 (the number of observation is multiplied by the coefficient of determination). This statistic follows $(M - K)$ degrees of freedom under the null hypothesis that error term is uncorrelated with the instruments. Here M = number of instruments and K = number of endogenous variable.

Table 12: Test of Over Identification Restriction

Model	**Sargan N*R^2 test(Chi-sq)**	**P-value**	**Basmann test (Chi-sq)**	**P-value**
Model 1	3.43(4)	0.49	3.2(4)	0.52
Model 2	2.86(3)	0.41	2.65(3)	0.45

Note: degrees of freedom in Parenthesize

The results show that the null hypothesis of over identification is uncorrelated with the instruments, what cannot be rejected. That is the models are over identified.

The test of endogeneity refers to the fact that all the instruments are uncorrelated with error term but correlated with endogenous variable. Here the endogeneity test for the models are done by Wu-Husman F test and Durbin-Wu-Husman Chi-sq test considering the null hypothesis

H0 = Regressor’s are exogenous and alternative hypothesis; H1= Regressor’s are endogenous. The result of the test is shown in the following table:

Table 13: Test of Endogeneity

Model	**Wu-Husman F test**	**P-value**	**Durbin –Wu-Husman Chi-sq test**	**P-value**
Model 1	0.22 (1, 54)	0.64	0.23 (1)	0.63
Model 2	0.50 (1, 53)	0.48	0.54 (1)	0.46

Note: Parenthesizes are degrees of freedom

The table shows that the results of both tests (Wu-Husman F test and Durbin-Wu-Husman Chi-sq test) are almost equal for both models with higher p-values. So, both forms of test show that estimating the equation with non linear regression (log-log) gives consistent results. Thus we cannot reject the null hypothesis of regressor's exogeneity. That is there is no endogeneity problem in the models.

Chapter-7: Discussion and Comparison of Results

Considering the estimated results from different regressions and tests in chapter six, we can conclude that model 1 and 2 are better models in this study. That is the instrumental variable (IV) regression is better than the Ordinary Least Square (OLS) regression. The reasons why the instrumental variable regression is better than the OLS estimator are, i) there is no multicollinearity and heteroskedasticity in instrumental variable regressions. Though there are few insignificant t statistics with high R^2 values show possibility of multicollinearity but the tests of auxiliary regression and VIF nullified the presence of multicollinearity; ii) the instrumental variable regressions are over identified and there is no endogeneity problem in these two models. As a result, these two instrumental variable regression models satisfy the properties of instrumental variable regression. On the other hand, the OLS estimator model 3 has multicollinearity problem in few variables. The variances of those variables are inflated over the actual variance; moreover model 3 has significant level of heteroskedasticity. Thus the instrumental variable regression models (model 1 and model 2) are suitable model for this study.

In order to make a comparison of the estimated results with other studies we differentiate the total cost function with respect to carbon sequestration to get the marginal cost. Using the estimated coefficient of Ln of carbon sequestration (LnCSS) from model 1, the calculated marginal cost as a function of carbon sequestration (CSS) is $13.30 and in model 2 it is $13.11 (Appendix E) remaining other things constant. We know the profit maximizing necessary condition is,

Marginal Cost (MC) = Marginal Revenue (MR)

But in a competitive market marginal revenue is equal to the price.

So, Marginal Cost (MC) = Price (P).

Thus equating marginal cost with price the estimation gives the price of per ton of sequestered carbon is $13.30 (model 1). Interestingly, we did not find any guideline in the Kyoto Protocol about the price and market structure of the carbon trading. Rather it emphasized on cost efficient carbon reduction by Annex I countries in Non-Annex I countries. As a result, no strong market behavior is observed in the carbon market; especially for price mechanism. Generally, the higher price of carbon can enhance more carbon sequestration as price change is expected to change the behavior of landowners (Bowen, 2011). That condition will lead carbon sequestrated countries can gain by the carbon trading. But the global carbon price is very low comparing with the abatement cost of the carbon reduction by the Annex I countries (Table 14) which is the shadow price. Ellerman et al. (1998) have calculated this shadow price equating the last ton of carbon abated (marginal cost) in absence of emission trading in those regions.

Table 14: Abatement Costs of Developed Countries

Country	**Abatement Cost/$t Co_2**
Japan	$584
EEC(12 Countries)	$273
OOE	$223
USA	$186

Notes: EEC = European Union, OOE = Other OECD Countries, USA = United States of America, *Source*: Ellerman et al., 1998

Thus the lower price of carbon resembles the lower benefits to the carbon sequestration supplier countries and in turns the lower supply of carbon sequestration. The price for carbon needs to be fixed in such a way that it resembles the marginal costs or marginal damages, while marginal damage is refers as the marginal social costs. Thus it is difficult to estimate because of uncertainties, such as future damages of atmosphere, warming and sea level rise (Bowen, 2011). In this regard, the policymakers need to be careful about the marginal social costs of carbon as it will determine the price of carbon. But it is clear that the carbon trading through carbon sequestration decreases the cost of emission reduction.

Here the calculated result shows the present market scenarios observed in 2009. According to State and Trend of Carbon Market Report of World Bank the carbon price in EUA (European Union Allowance) plummeted to €8 (US$ 11.7) in February 2009 and in May it ranges from €13 to € 16 (US$ 17 to US$ 22) (Kossy and Ambroisy, 2010). Diaz et al. (2010) reported that in Chicago Carbon Exchange Market the exchange price was $7.0/t CO_2e in May 2008 and it declined to $0.1/t CO_2e in 2009. On the other hand, the UK Committee on Climate Change has projected per ton of carbon price is $47.79 (£30) in 2020 and $111.52 (£70) in 2030 (Bowen, 2011) in terms of US$ 2005. Thus the result estimated in this study is consistent with the present scenario of the carbon market. Irrespective of the price and market mechanism, still the carbon sequestration is profitable but with a proper market mechanism it could be a more profitable sector of land use in developing countries. It will then benefit the developing countries through foreign earnings and reduce the cost of carbon reduction of developed countries. At the same time global carbon reduction target could be achieved by this cost effective measure.

Chapter-8: Conclusion

This study has found that the percentage change of carbon sequestration cost due to the percentage change in carbon sequestration is close to unitary. That is the elasticity of carbon sequestration cost is almost unitary and linear. In this case the marginal cost of carbon sequestration is equal to the average cost of carbon sequestration. As the average cost and marginal costs are equal the production function is constant returns to scale. Constant return to scale refers that the output changes is proportional to the change in inputs. The reason for unitary elasticity of carbon sequestration cost might be for constant returns to scale of carbon sequestration. Though initial cost of conversion of land and plantation is high, the cost decreases while the length of time increases and finally the sequestration depends only on the maintenance costs of carbon sequestration. The marginal cost and price calculated (Chapter 7: Appendix E) in this study from cost function shows that the price represents the present market scenario. The estimated marginal cost of carbon sequestration is very low comparing the abatement costs of developed countries (Annex I) meaning that carbon sequestration is a cost effective way to reduce carbon emission. Thus this can reduce global costs of emission reduction and increase earnings for developing countries

On the other hand, this study has some shortcomings like the unavailability of data. The data on the price of sequestrated carbon was the major shortcomings of this study. In addition, unavailability of updated data on carbon sequestration from a singular unified source and small size of sample among others are some shortcomings of this study. Hence this study could not estimate the derived demand function or derived supply function of carbon sequestration because of unavailability of data on price of carbon sequestration though the theoretical background was started with the profit maximizing behavior of the land owners. This is why we have estimated the carbon sequestration cost function. But the matter of hope is that, the carbon sequestration data is not rich enough globally as it is a new phenomenon in the global economy. Despite of these limitations, this study gives a cost scenario which could be helpful for further research and policy matters. Irrespective of some shortcomings this study seeks to estimate the carbon sequestration cost function for developing countries which may be helpful to the global policymakers for emission reduction through carbon sequestration as an effective measure.

This study revealed that the price of carbon needs to be a bit higher as a regulated price. In the regulated price it could be higher than the marginal cost of sequestration. UNFCCC can play a vital role in fixing the regulated price so that both parties (Annex I and Non-Annex I countries) could gain from the carbon sequestration in terms of equity. In addition to regulated price, the Annex I countries can contribute building social infrastructure in Non-Annex countries to improve the livelihood as compensation.

The global concern for emission reduction increases the demand for carbon sequestration. Thus project based carbon sequestration is increasing in tropical developing countries as it is a cost effective way of emission reduction among others. Especially, carbon sequestration reduces the cost of emission reduction for developed countries (Annex I countries) more sharply than their abatement cost. Simultaneously, it has opened an opportunity for Non-Annex I countries to earn foreign remittance by employing some of their land in carbon sequestration projects. Estimating the carbon sequestration cost function this study found that the carbon sequestration is a constant return to scale. This finding means that the carbon sequestration is a profitable source of land uses in developing countries, i.e. Non-Annex I countries. Once again, this study identified the three fold benefits of carbon sequestration, which may help to meet the global emission reduction target.

References

Books and Articles

Aldrich, J. 1993 “Reiersøl, Geary and the Idea of Instrumental Variables” The Economic and Social Review 24(3), pp. 247-273

Bettelheim, E. C. and D’Origny, G. (2002**)** “Carbon Sinks and Emission Trading under Kyoto Protocol: A Legal Analysis” The *Royal Society*, 360, pp. 1827-1851

Bloomfield, J., and Pearson, H. L. (2000) “Land Use, Land-use Change, Forestry, and Agricultural Activities in the Clean Development Mechanism: Estimates of Greenhouse Gas Offset Potential”, *Mitigation and Adaptation Strategies for Global Change*, 5(1), pp. 9–24

Bowen, A. (2011) “The Case for Carbon Pricing” Policy brief, Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science

Brown, S. (1996) “Mitigation Potentials of Carbon Dioxide Emissions by Management of Forests in Asia.” *Ambio*, 25(4), pp. 273-278

Ellerman, A. D. and Decaux, A. (1998) “Analysis of Post-Kyoto CO2 Emissions Trading Using Marginal Abatement Curves” MIT Joint Program on the Science and Policy of Global Change, Report 40, Cambridge, Massachusetts

Ellerman, A. D., Jacoby, H. D. and Decaux, A. (1998) “*The effects on developing countries of the Kyoto protocol and co2 emission trading”* World Bank Policy Research Working Paper No. 2019

Hay, J., Yvo de, B., Kononov, S., Ethaddad, M. and Simeonova,K., (2007) *Making Kyoto work: data, policies, infrastructures* UNFCC Press briefing ,DeutscheWelle, Bonn, Germany

Gujarati, D. N., 2004 “Basic Econometrics 4th edition” The McGraw-Hill Companies

Hossain, M.A., Alam, M. A., Rahman, M. M., Rahaman, M. A., and Nobi, M.N. (2006) "Financial variability of shifting cultivation versus agroforestry Project: A case study in Chittagong Hill Tracts", *International Journal of Agriculture and Biology,* 8(1), pp. 29-34

Kapoor, K. and Ambrose, P. (2006) "State and Trends of the carbon market 2006" World Bank

Kopp, R. J. (2011) "If Walmart Were In Charge: Sourcing CO2 Emissions Reductions at Least Cost" Resources for the Future, Issue Brief 11-14

Kaya, Y., 1990 "Impact of carbon dioxide emission control on GNP growth: interpretation of proposed scenarios'', IPCC Energy and Industry subgroup. Response Strategies Working Group, Paris, France (Mimeo)

Kossoy, A and Ambrosi, P. (2010) "State and Trends of the Carbon Market 2010" World Bank

Lubowski, R. N., Plantinga, A. J. and Stavins R.N. (2006) "Land-use Change and Carbon Sinks: Econometric Estimation of the Carbon Sequestration Supply Function." *Journal of Environmental Economics and Management*, 51(2), pp: 135–152

Makundi, W. R., and Okiting'ati, A. (1995) "Carbon Flows and Economic Evaluation of Mitigation Options in Tanzania's Forest Sector" *Biomass and Bioenergy*, 8(5), pp. 381–393

Masera, O. R., Bellon, M. R. and Segura, G. (1995) "Forest Management Options for Sequestering Carbon in Mexico", *Biomass and Bioenergy*, 8(5), pp. 357–367

Moulton R. J. and Richards K. R (1990) "Costs of Sequestering Carbon Through Tree Planting and Forest Management in the United States" U.S Department of Agriculture Forest Service, General Technical Report WO-58, Washington DC

Newell, R. G. and Stavins R. N. (1999) "*Climate Change and Forest Sinks: Factor Affecting the Costs of Carbon Sequestration*" Discussion Paper 99-31-REV, Resources for the Future, Washington DC, USA

Niles,J. O., Brown, S., Pretty J., Ball, A. S. and Fay, J. (2002) “Potential Carbon Mitigation and Income in Developing Countries from Changes in Use and Management of Agricultural and Forest Lands.” *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* 360(1797), pp. 1621–1639.

Pfaff, A. and Kerr, S. (1999) “*A Carbon Sequestration Supply Function and Development of Feasible Clean Development Mechanism Rules for Tropical Forest Carbon Sinks”* Working Paper No.9899-08, Department of Economics, Colombia University, USA

Pfaff. A. S. P., Kerr S., Hughes, R., Lie S., Sanchez-Azofeifa G., Schimel D., Tosi J. and Watson V. (2000) “ The Kyoto Protocol and payments for tropical forest: An interdisciplinary method for estimating carbon-offset supply and increasing the feasibility of carbon market under the CDM” *Ecological Economics,* 35(2), pp.203-221

Ravindranath, N. H. and Somashekhar,B. S. (1995) “Potential and Economics of Forestry Options for Carbon Sequestration in India.” *Biomass and Bioenergy,* 8(5), pp. 323–336

Richards, K. R., and Stokes, C. (2004) “A Review of Forest Carbon Sequestration Cost Studies: a Dozen Years of Research.” *Climatic Change,* 63(1), pp. 1–48

Rokityanskiy D., Benítez P.C., Kraxner F., McCallum I., Obersteiner M, Rametsteiner E., and Yamagata Y. (2007) “Geographically Explicit Global Modeling of Land-use Change, Carbon Sequestration, and Biomass Supply.” *Technological Forecasting and Social Change,* 74(7), pp. 1057–1082.

Sargan, J. D., 1958 “The Estimation of Economic Relationships using Instrumental variables” Econometrica 26, PP. 393-415, North-Holland Publishing Co. Amsterdam

Schulte, RPO. and Lanigan, G. (2011) “Irish Agriculture, Greenhouse Gas Emissions and Climate Change: opportunities, obstacles and proposed solutions” Teagasc (The Irish Agriculture and Food development Authority) Oak Park, Carlow.

Sedjo, R., Sohngen, B. and Mendelsohn, R. (2001) "Estimating Carbon Supply Curves for Global Forests and Other Land Uses" Discussion Paper 01–19, Resources for the Future

Smith, J and Scherr, S. J. (2002) "Forest Carbon and Local Livelihoods: Assessment of opportunities and Policy Recommendations" Centre for International Forestry Research, paper no. 37

Stavins, R. N. (1999) "The Costs of Carbon Sequestration: a Revealed-preference Approach." *The American Economic Review,* 89(4), pp. 994–1009

Stavins R. N. and Richards K. R. (2005), "The cost of U.S. forest-based carbon sequestration" Pew Center on Global Climate Change, Washington, D.C

Stock, J. H and Watson, M. W. 2006 "Introduction to Econometrics 2nd Edition" Pearson addisons and Wesley (Published by Prentice Hall)

Sugden, C. (2010) "Carbon Footprint of Agricultural Development: the Potential Impact of Uptake of Small Electric and Diesel Pump in Five Countries in Sub Saharan Africa" Stockholm Environmental Institute, Working Paper-2010

Werf, G. R., Randerson,J.T., Giglio, L., Collatz, G. J., Kasibhatla, M. Mu, P. S., Morton, D. C. , DeFries, R. S., Jin,Y. and Leeuwen, T.T. (2010) "Global Fire Emissions and the Contribution of Deforestation, Savanna, Forest, Agricultural, and Peat Fires (1997-2009)" Atmospheric Chemistry and Physics, 10(6), pp. 16153–16230

Reports

Carbon Finance Annual Report 2011, Carbon Finance for Sustainable Development, World Bank also available at http:// siteresources.worldbank.org /INTCARBONFINANCE /Resources/2012_Carbon_Finance_2011_AR_WEB_OPT.pdf [Date accessed June 20, 2012]

Deveny, A., Nackoney, A., Purvis,N., Gusti, M., Kopp, R. J., Madeira, E. M., Stevenson A. R.., Kindermann, G., Macauley, M. K. and Obersteine, M. (2009) " *The Geography of Forest in Climate Solutions" Resources for the Future, Report* 2009.

Diaz, D., Hamilton , K. and Johnson, E. (2011) "State of Forest Carbon Markets 2011, From Canopy to Currency" Ecosystem Marketplace, Forest Trends

World Soil Resources Report No. 92, Food and Agriculture Organization of The United Nations, (2000) "*Carbon Sequestration Options Under the Clean Development Mechanism to Address Land Degradation*." Rome

WebPages

CDM pipeline [Date accessed April 12, 2012] also available at http://www.cdmpipeline.org/

Ecosmagazine (Date accessed11/04/2012) also available at http://www.ecosmagazine.com /paper/EC10048.htm

Global Forest Watch (Date accessed 2012/04/11) available on http://www. Global forestwatch.org /english/indonesia/forests.htm

Health Guidance: Blumentha, F. "Sustainable Agriculture in Developing Countries-Challenges and U.S. Role" [Date accessed on 15/04/2012] also available at http://www. healthguidance.org/entry/6226/1/Sustainable-Agriculture-in-Developing-Countries-Challenges-and-US-Role.html

IPCC [Date accessed on April 5, 2012] also available at http://www.grida.no /publications/ other/ipccsr/?src=/climate/ipcc/emission/050.htm

McDowel, N. (2002) "Developing countries to gain from carbon-trading fund" Nature 420(4) also available at http://www.nature.com/nature/journal/v420/n6911/full/420004a.html [Date accessed on February 10, 2012]

Mongaby[Date accessed June 15, 2012] also available at www.rainforests.mongabay.com /deforestation/

TEEIC [Date accessed May 09, 2012] also available at http://teeic.anl.gov/er/carbon /carboninfo/reduce/index.cfm

The Dictionary of Sustainable Management [Date accessed on September 20, 2012] also available at www.sustainabilitydictionary.com/the-kaya-identity/

UNEP Riso Centre [Date accessed on May 16, 2012] also available at http://www. uneprisoe.org/Default.aspx

UNFCCC [Date accessed on April 16, 2012] also available on **www.**cdm.unfcc.intOfficial

UNSTATS [Date accessed on July 12, 2012] also available at http://unstats. un.org /unsd /methods/icp/ipc7_htm.htm

Appendices

Appendix A: List of Countries in Sampling

Afghanistan, Argentina, Angola, Bangladesh, Benin, Bolivia, Botswana, Brazil, Burkina Faso, Burundi, Cambodia, Cameron, Central African Rep, Chile, Chad, China, Colombia, Costa Richa, Cote dÍvoire, Dem. Rep.Congo, Dominucan Rep, Ecuador, Ethopia, Guatemala, Guyana, Honduras , India, Indonesia, Kenya, Laos, Madagascar, Malaysia, Mali, Mexico, Mozambique, Morocco, Myanmar, Nepal, Nicaragua, Niger, Nigeria, Pakistan, Panama, Papua New Guinea, Paraguaya, Peru, Philipines, Senegal, South Africa Sudan, Srilanka, Tanzania, Thailand, Uganda, Venezuela, Vietnam, Zambia and Zimbabwe.

Appendix B: Average Unit Cost of carbon sequestration missing in the Forest Carbon Index (2009) were considered as the average of the neighboring countries/ equivalent to some neighboring countries as follows:

Target Country	**Consideration**	**Target Country**	**Consideration**
Vietnam, China	Equivalent to Laos	India	Average of Pakistan, China, Nepal and Bangladesh
Morocco	Average of Mali, Chad, Senegal and Benin	Sri Lanka	Average of India, Myanmar, Thailand and Malaysia
Ivory Cost, Niger, South Africa	Average of Namibia, Zimbabwe and Botswana	Thailand	Average of Vietnam, Indonesia, Laos
Chile	Average of Brazil, Bolivia, Mexico and Paraguay		

Appendix C

Carbon Sequestration data for following countries were collected from Devney et al. (FCI, 2009): Afghanistan, Argentina, Burundi, Cambodia, Chile, Dominican Rep, Morocco and Nepal

Appendix D

Afforestation/Reforestation data for the following countries were collected from FAO Forest data: Afghanistan, Argentina, Burundi, Cambodia, Chile, Dominican Rep, Morocco, Nepal, Pakistan and Sri Lanka

Appendix E: Calculating Marginal Cost (Model 1)

$$\ln(TC) = \alpha_1 + \alpha_2 \ln(CSS) + \alpha_3 \ln(GDP)$$

$$\Rightarrow \frac{1}{TC}\frac{\partial(TC)}{\partial(CSS)} = \frac{\partial}{\partial(CCS)}\{\alpha_1 + \alpha_2 \ \ln(\text{CSS}) + \alpha_3 \ln(\text{GDP})\}$$

$$\Rightarrow \frac{1}{TC}\frac{\partial(TC)}{\partial(CSS)} = \alpha_2 \frac{1}{\text{CSS}}$$

$$\Rightarrow \frac{\partial(TC)}{\partial(CSS)} = \alpha_2 \frac{\text{TC}}{\text{CSS}}$$

Since $\frac{\partial(TC)}{\partial(CSS)}$ =MC and $\frac{\text{TC}}{\text{CSS}}$ =AC

MC=$\alpha_2 \times$ AC $= f(CSS) = f(CSS)$

Thus, $MC = \alpha_2 * AC$

$\Rightarrow MC = 0.997 * AC$

$\Rightarrow MC = (0.997 * 13.34)$ (Assumption: Putting AC = Mean of AC)

$\Rightarrow MC = \$ 13.30$

Calculating Marginal Cost (Model2)

$MC = \alpha_2 * AC$

$\Rightarrow MC = 0.983 * AC$

$\Rightarrow MC = (0.983 * 13.34)$

$\Rightarrow MC = \$ 13.11$