Feasibility Study for Estimating the Cost of Carbon Sink in Korea

SoEun Ahn
KiJoo Han
Abstract

The Kyoto Protocol and the Marrakesh Accords to the Framework Convention on Climate Change recognize Land Use, Land-Use Change, and Forest (LULUCF) activities - mainly afforestation and reforestation - as a potential means to reduce greenhouse gases in atmosphere, and, thus, to meet the emission reduction targets allocated to the developed countries. In recent years, LULUCF activity, commonly referred to as carbon sink management, has received a great deal of attention internationally, and many researches have been conducted in this area.

Despite the increasing attention to carbon-sink management under climate change negotiation process and research arena, not much consideration is given to carbon-sink management in Korea except for the construction of necessary statistics on the greenhouse gas emissions and removals by LULUCF activities in National Communication under the Convention.

The purpose of this study is to evaluate the feasibility of utilizing an econometric land use model to estimate the costs of carbon-sink programs in Korea. In literature, most of the economic studies of carbon-sink management evaluate the government policy, which is designed to encourage the conversion of agricultural and/or marginal land to forest. A similar approach will be employed in this study.

Note that, however, this study aims to investigate the potential use of empirical land use model to assess the carbon-sink program. Therefore, the scope of the study is limited to literature review on subjects and to examination of the data availability to estimate the model. Actual model estimation and simulation on calculating the costs of carbon-sink programs are planned to be proceeded in the subsequent study.

The literature review in this study is divided into two parts. The one is the literature survey on the researches that connect land use changes with carbon fixation capabilities, and the other part is on the economic studies which link the econometric land use model to carbon fixation and to policy assessment. The inspection on the data availability is carried out in two steps, too. We, first, identify the variables required for the estimation of model based on the literature review on the economic studies. Once the
variables are identified, the next step is to check if the data are available to construct each variable. We concentrate on the databases published by the various government sectors.

The results of this study are summarized as follows. We find out that, in Korea, the researches on land use change and carbon-fixation capability are relatively well documented and the related data are well accumulated. The main source of information for this part is Korea Forest Research Institute (KFRI). KFRI in collaboration with Korea Forest Service prepares LULUCF section of National Communication and provides the statistics on greenhouse gas emissions and removals associated with LULUCF activities. The information on this part is important because it determines the quantity of carbon stored in unit area which will be, in turn, put into the simulation to compute the cost of carbon sink program. Therefore, a special care should be given to the assumptions made in computing the statistics on greenhouse gas emissions and removals associated with LULUCF activities.

An econometric land use model, typically, employs the panel data to reflect the temporal and spatial changes in land use patterns and recognizes relative rents among competing uses, land quality, population, distance to the city as the key factors that affect land use change. Constructing the key variables mentioned above in panel data format requires pre-determination on the units of time-series and cross-sectional data series. Based on the results of data review, we find that most data are collected in yearly basis; thus, it is reasonable to arrange the time-series observations annually. For the spatial unit, however, we realize that the coverage of available data varies. For instance, some data scale down only to broad administrative regions, and some data scale down further in detail. Important task in assembling panel data is maintaining the consistency of time-series and cross-sectional observation unit, and determining the appropriate cross-sectional unit needs a further consideration.

In conclusion, if we put aside the statistical significance of the model estimates, application of an econometric land use model to estimate the costs of carbon-sink program is feasible in Korea. The success of the subsequent study will depend on the quality of data and the flexibility and robustness of the model.
Contents

Abstract

Chapter 1. Introduction ................................................. 1

Chapter 2. Land Use Changes and Greenhouse Gases .......... 3
  1. Kyoto Protocol and Land-Use Change .......................... 3
  2. IPCC Guidelines: Land-Use Change Sector ......................... 4
  3. Greenhouse Gas Inventory: Land-Use Change Sector ................. 7

  1. Land Use Model ..................................................... 11
  2. Determinants of Land Use and Data ................................ 15
  3. Simulation for Estimating the Costs of Carbon-Sink ................. 17

Chapter 4. Feasibility for Estimating the Costs of Carbon-Sink .......... 18
  1. Historical Trends of Land Use in Korea .......................... 18
  2. Data ........................................................................ 19

Chapter 5. Conclusion ...................................................... 21

Reference ................................................................. 22
List of Tables

Table 2-1 Forest Land Area and Growing Stock ........................................ 8
Table 2-2 Forest Area by Forest Type ...................................................... 8
Table 2-3 Net Greenhouse Gas Emissions/Removals from
Land Use Change and Forestry ............................................................. 9
Table 2-4 Emissions/Removals from Land-Use Change and Forestry
by Category (2001) ............................................................................... 10
Table 4-1 Historical Trends of Land Use in Korea ................................. 18
Table 4-2 Conversion of Agricultural Land .............................................. 18
Table 4-3 Conversion of Forest Land ......................................................... 19

List of Figures

Figures 2-1 Definitions of LULUCF Activities ......................................... 4
Chapter 1. Introduction

The Kyoto Protocol and the Marrakesh Accords to the United Nations Framework Convention on Climate Change (UNFCCC) recognize Land Use, Land-Use Change, and Forest (LULUCF) activities - mainly afforestation and reforestation - as a potential means to reduce greenhouse gases in atmosphere, and, thus, to meet the emission reduction targets allocated to the developed countries.

In recent years, LULUCF activity, commonly referred to as carbon sink management, has received a great deal of attention internationally, and many researches have been conducted in this area. Intergovernmental Panel on Climate Change published the special report Land Use, Land-Use Change, and Forestry (IPCC, 2000) to provide a comprehensive state-of-art examination of the scientific and technical implication of carbon sequestration and issued Good Practice Guidance for Land Use, Land-Use Change, and Forestry (IPCC, 2003) to supply methods for estimating, measuring, monitoring and reporting on greenhouse gas inventory from LULUCF activities.

Along with the effort of IPCC, some economists have taken economic approaches to analyze the carbon sequestration policy. Most of the economic studies of carbon sink management employ either simulation technique (Moulton and Richard (1990); Admas et al. (1993); Parks and Hardie (1995)) or econometric land use models (Stavins (1999); Plantinga and Miller (1999)).

Despite the increasing attention to carbon-sink management under climate change negotiation process and research arena, not much consideration is given to carbon-sink management in Korea except for the construction of necessary statistics on the greenhouse gas emissions and removals by LULUCF activities in National Communication under the Convention.

The purpose of this study is to evaluate the feasibility of utilizing an econometric land use model to estimate the costs of carbon-sink programs in Korea. In literature, most of the economic studies of carbon-sink management evaluate the government policy, which is designed to encourage the conversion of agricultural and/ or marginal
land to forest. A similar approach will be employed in this study.

Note that, however, this study aims to investigate the potential use of empirical land use model to assess the carbon-sink program, and, therefore, the scope of the study is limited to literature review on subjects and to examination of the data availability to estimate the model. Actual model estimation and simulation on calculating the costs of carbon-sink programs are planned to be proceeded in the subsequent study.

The literature review in this study is divided into two parts. The one is the literature survey on the researches that connect land use changes with carbon fixation capabilities, and the other part is on the economic studies which link the econometric land use model to carbon fixation and to policy assessment. The inspection on the data availability is carried out in two steps, too. We, first, identify the variables required for the estimation of model based on the literature review on the economic studies. Once the variables are identified, the next step is to check whether the data are available to construct each variable. We concentrate on the databases published by the various government sectors.

This report consists of 5 chapters. Chapter 2 considers Kyoto protocol and land use change, IPCC guideline to construct the greenhouse gas inventory, and greenhouse gas inventory statistics based on the second National Communication submitted to UNFCCC by Korea. Chapter 3 introduces an econometric land use models and examines the required data to estimate the model. Chapter 4 investigates the feasibility of applying the model introduced in the Chapter 3. The Chapter 5 includes the summary and conclusion of the study.
Chapter 2. Land Use Change and Greenhouse Gases

1. Kyoto Protocol and Land Use Change

The Kyoto Protocol, adopted at the 3rd session of Conference of Parties (COP-3) in 1997, makes provision for the developed countries (Annex I Parties) to take into account afforestation, reforestation, and deforestation and other agreed land use, land-use change, and forestry (LULUCF) activities in meeting their commitments under Article 3. Marrakesh Accords, adopted at the COP-7, set the specific rules to implement LULUCF activities under the Kyoto Protocol. According to Marrakesh Accords, the definitions of forest, afforestation, reforestation, and deforestation are as follow (http://unfccc.int):

Forest is a minimum land area of 0.05-1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10-30 percent with trees with the potential to reach minimum height of 2-5 meters at maturity in situ. Young natural stands and all plantations, which have yet to reach a crown density of 10-30 percent of tree with height of 2-5 meters are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as the results of human intervention such as harvesting or natural causes but which are expected to revert to forest.

Afforestation is the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources.

Reforestation is the direct human-induced conversion of non-forested land to forested land through planting, seeding, and/or the human-induced promotion of natural seed sources on land that was forested but that has been converted to non-forested land. For the first commitment period (2008-2012), reforestation activities will be limited to reforestation occurring on those lands that did not contain forest on December 31, 1989.
Deforestation is the direct human-induced conversion of forested land to non-forested land.

Figure 2-1 visualizes the definition of each activity described above.

**Figure 2-1. Definitions of LULUCF Activities**

Note: (a), (b), and (c) represent afforestation, reforestation, and deforestation, respectively.

Source: Land Use, Land-Use Change, and Forestry (IPCC, 2000)

### 2. IPCC Guidelines: Land-Use Change Sector

Upon the request from UNFCCC, IPCC published Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines from here to below) (IPCC, 1996), and the Parties agreed to use IPCC Guidelines to estimate greenhouse gas emissions and removals in preparing their National Communication reports. This section summarizes the basic approaches taken in IPCC Guidelines and describes the priority categories considered in estimating the effects of LULUCF activities on the emissions of greenhouse gases.
Methodology

The methodology employed in IPCC Guidelines is designed to be comprehensive (i.e. to cover all of the main land-use change and forestry activities) and to be feasible to implement by all participating countries. It can be implemented at several different levels of complexity and geographic scales, depending on the circumstances each country faces and capabilities of national experts in different countries. It seems that there are three different approaches that each country can adopt.

First approach is based on very aggregate default data and assumptions provided in IPCC Guidelines. These aggregate default data and assumptions are derived from international organization such as Food and Agriculture Organization (FAO) and various technical literatures. This approach is appropriate for the countries where the related data are not well established. It is important to note, however, that many of the default data provided by IPCC can be highly uncertain because there is a good possibility that suggested default values vary significantly from region to region. This one-size-fit-all concept does not reflect unique circumstances of each country and probably does not provide a basis for a credible final inventory. National experts in forestry and related fields should be consulted to determine the most appropriate values for use in national inventories.

Second approach provides a way in which more accurate data can be constructed. This approach simply substitutes country-specific values for general defaults provided. If local data are available and reliable, they can be used to carry out calculations at a more detailed geographic scale and/or subcategory level. It is strongly recommended that national experts are to examine the quality of data and to substitute more appropriate (i.e. country or region-specific) and more detailed input data wherever they are available.

Third and the most desirable approach uses forest inventory data developed by each country. Some countries, which had maintained

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1 The methodology described in this section is summarized based on the chapter 5 in Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual (IPCC, 1996)
rich forests historically tend to develop their own periodic inventory survey system and keep the records on various information on forest resources.

Usually forest inventory include the data not only on land-use change over time but also on forest management activities. With detailed inventory based data, national experts can re-format and analyze these data to derive greenhouse gas emissions and removals by LULUCF activities.

In sum, the choice of approach to estimate greenhouse gas inventory associated with LULUCF activities is likely to depend on the data availability. As described above, IPCC Guidelines provides a spectrum of approaches that are comprehensive in the scope and feasible to be implemented by all participating countries according to their unique situations.

Priority Criteria

In estimating the effects of land use and land-use changes on the emissions of greenhouse gases, it is reasonable to design the calculation methods so that the most important components can be addressed first. On a global scale, the most important land-use changes that result in $CO_2$ emissions and removals are:

**Changes in forest and other woody biomass stocks:** the most important effects of human interactions with existing forests are considered in a single broad category, which includes commercial management, harvest of industrial roundwood(logs) and fuel-wood, production and use of wood commodities, and establishment and operation of forest plantations as well as planting of trees in urban, village and other non-forest locations.

**Forest and grassland conversion:** the conversion of forests and grasslands to pasture, cropland, or other managed uses can significantly change carbon stored in vegetation and soil.

**Abandonment of croplands, pastures, plantation forests, or other managed lands,** which re-grow into their prior natural grassland or
7 Land-Use Change and Greenhouse Gases

Changes in soil carbon: the principle sources/ sinks of CO$_2$ in soils are associated with changes in the amount of organic carbon stored in soils. Release of CO$_2$ also occurs from inorganic sources, either from naturally occurring carbonate minerals or from applied lime.

In preparing greenhouse gas inventory data to produce National Communications associated LULUCF activities, CO$_2$ emissions and removals from the 4 categories described above are to be reported.

3. Greenhouse Gas Inventory: Land-Use Change Sector

This section includes the characteristics of Korean forest, the historical trends of CO$_2$ emissions and removals associated with LULUCF activities.$^2$

Korean peninsula is located between 125°04’ and 131°52’ east longitude and between 36°06’ and 38°27’ north latitude. As of 2001, the total land area of Korea is 99,954 km$^2$, where forest and agricultural and comprise 65% and 19% of total land, respectively.

Korea’s forests are of the cool-temperate and warm-temperate zones. The warm-temperate zone is located the south of 35° north latitude where the annual mean temperature is over 14°C. This area includes part of the southern coastal regions and the islands off the coast as well as Juju Island. The forest in this area is characterized by dense broad-leaf evergreen consisting of Quercus acuta, Camellia japonica, Cinnamomum camphora etc. The cool-temperate zone lies between the 35°- 45° north latitude where the annual mean temperature is 6-14°C. Most of Korea belongs to cool-temperate zone where the forests are dominated by broad-leaved deciduous species such as Quercus spp., Acer spp., Fraxinus spp. and by coniferous trees such as Pinus densiflora and Pinus koraiensis.

Although 65% of the total land area in Korea is covered by forests, 87%

$^2$ The content of this section is summarized from Second National Communication of the Republic of Korea Under the United Nations Framework Convention on Climate Change (Government of the Republic of Korea, 2003)
of the trees are less than 30 years old and have not yet reached full maturity. Table 2-1 shows the historical change in forest area, total growing stock, and growing stock per hectare in Korea. Forest area has decreased, in general, since 1970, but is relatively stable during the last decade. Growing stock, however, has significantly increased over the past 30 years.

**Table 2-1. Forest Land Area and Growing Stock**

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (1,000 ha)</th>
<th>Growing Stock (1,000 m$^3$)</th>
<th>Growing Stock per Hectare (m$^3$/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>6,611</td>
<td>66,750</td>
<td>10.07</td>
</tr>
<tr>
<td>1980</td>
<td>6,568</td>
<td>145,694</td>
<td>22.18</td>
</tr>
<tr>
<td>1990</td>
<td>6,476</td>
<td>248,426</td>
<td>38.36</td>
</tr>
<tr>
<td>2000</td>
<td>6,422</td>
<td>407,575</td>
<td>63.47</td>
</tr>
<tr>
<td>2001</td>
<td>6,415</td>
<td>428,346</td>
<td>66.77</td>
</tr>
</tbody>
</table>

*Source: Yearbook of Forest Statistics, in various years (Korea Forest Service)*

Table 2-2 represents the changes in forestland areas by forest type. As of 2001, roughly the half of the forestlands consists of coniferous forests and the remainder is composed of broad-leaved forests and mixed forests. The area of coniferous forests in Korea has been continuously diminishing while the area of broad-leaved forest has been increasing over years due to natural succession.

**Table 2-2. Forest Area by Forest Type**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total (1,000 ha)</th>
<th>Coniferous (1,000 ha)</th>
<th>Broad-leaved (1,000 ha)</th>
<th>Mixed (1,000 ha)</th>
<th>Bamboo (1,000 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>5,700 (100)</td>
<td>3,268 (57.3)</td>
<td>1,207 (21.2)</td>
<td>1,219 (21.4)</td>
<td>6 (0.1)</td>
</tr>
<tr>
<td>1980</td>
<td>6,301 (100)</td>
<td>3,249 (51.6)</td>
<td>1,148 (18.2)</td>
<td>1,899 (30.1)</td>
<td>5 (0.1)</td>
</tr>
<tr>
<td>1990</td>
<td>6,286 (100)</td>
<td>3,079 (49.0)</td>
<td>1,389 (22.1)</td>
<td>1,810 (28.8)</td>
<td>8 (0.1)</td>
</tr>
<tr>
<td>2000</td>
<td>6,268 (100)</td>
<td>2,711 (43.2)</td>
<td>1,666 (26.6)</td>
<td>1,885 (30.1)</td>
<td>6 (0.1)</td>
</tr>
<tr>
<td>2001</td>
<td>6,266 (100)</td>
<td>2,692 (43.0)</td>
<td>1,672 (26.7)</td>
<td>1,896 (30.2)</td>
<td>6 (0.1)</td>
</tr>
</tbody>
</table>

*Note: numbers in parentheses are the percentages*

*Source: Yearbook of Forest Statistics, in various years, (Korea Forest Service)*
Table 2-3 illustrates the trends of net greenhouse gas emission/removals from land-use change and forestry in Korea. During the last decade, the net removals from “change in forest and other woody biomass stocks” increased due to the steady increase of forest growth and low level of harvesting. On the other hand, progress in urbanization led to increase in carbon dioxide emissions from soil due to land-use change, nevertheless the increase is minimal compared to the net removal from “changes in forest and other woody biomass stocks.” As such, the total net removal from land-use change and forestry increased from 6.5 MtC in 1990 to 9.5 MtC in 2001, indicating 3.5% growth per year.

Table 2-3. Net Greenhouse Gas Emissions/Removals from Land-Use Change and Forestry

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>-6,476</td>
<td>-5,793</td>
<td>-9,949</td>
<td>-10,422</td>
<td>-10,156</td>
<td>-9,448</td>
<td>3.5</td>
</tr>
<tr>
<td>1)</td>
<td>-7,155</td>
<td>-6,867</td>
<td>-11,087</td>
<td>-11,552</td>
<td>-11,299</td>
<td>-10,610</td>
<td>3.6</td>
</tr>
<tr>
<td>2)</td>
<td>46</td>
<td>71</td>
<td>82</td>
<td>84</td>
<td>84</td>
<td>88</td>
<td>6.0</td>
</tr>
<tr>
<td>3)</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
<td>-</td>
</tr>
<tr>
<td>4)</td>
<td>633</td>
<td>1,003</td>
<td>1,057</td>
<td>1,046</td>
<td>1,059</td>
<td>1,074</td>
<td>4.9</td>
</tr>
</tbody>
</table>

Note: Negative signs denote removals (or sink); GR represent annual growth rate; 1) Changes in Forest and Other Woody Biomass Stocks; 2) Forest and Grassland Conversion; 3) Abandonment of Managed Land; 4) CO₂ Emissions and Removals from Soil

Source: Yearbook of Forest Statistics, in various years, (Korea Forest Service)

Table 2-4 shows emissions/removals by land-use change and forestry by categories in 2001. The net removals from land-use change and forestry show that approximately 9.5 MtC of carbon dioxide has been absorbed in this category. The records indicate the removals of 10.6 MtC from “changes in forest and other woody biomass stocks,” whereas 88,000 tC and 1.1 MtC were emitted, respectively, from “forest and grassland conversion” and “CO₂ emissions and removals from soil.” We assume that “abandonment of managed land” area is negligible because the land competition in Korea is very high due to large population. The similar reasoning applies to “other” category.
Table 2.4. Emissions/Removals from Land-Use Change and Forestry by Category (Year: 2001)

<table>
<thead>
<tr>
<th>Greenhouse Gas Source &amp; Sink Categories</th>
<th>CO₂ Emissions (1,000 tC)</th>
<th>CO₂ Removals</th>
<th>CO₂ Net E/R*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changes in Forest and Other Woody Biomass Stocks</td>
<td>2,121</td>
<td>- 11,569</td>
<td>- 9,448</td>
</tr>
<tr>
<td>Forest &amp; Grassland Conversion</td>
<td>959</td>
<td>- 11,569</td>
<td>- 10,610</td>
</tr>
<tr>
<td>Abandonment of Managed Land</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
</tr>
<tr>
<td>CO₂ Emissions &amp; Removals from Soil</td>
<td>1,074</td>
<td>0</td>
<td>1,074</td>
</tr>
<tr>
<td>Others</td>
<td>NE</td>
<td>NE</td>
<td>NE</td>
</tr>
</tbody>
</table>

Note: *: Emissions/Removals; Negative signs denote removals (or sink);
Source: Yearbook of Forest Statistics, in various years (Korea Forest Service)

Throughout this chapter, we find out that, in Korea, the researches on land-use change and carbon-fixation capability are relatively well documented and the related data are well accumulated. Korea Forest Service (KFS) conducted a comprehensive periodical inventory survey on forest resources four times since 1970. In addition, KFS publishes Yearbook of Forest Statistics annually based on the sampling and provides various information including land area by forest type, growing stock, commercial harvest, import and export of forest precuts etc.

Well-established forest statistics enables Korea to adopt the third approach suggested in IPCC Guidelines, which is based on country's own inventory data. In collaboration with KFS, experts at the Korea Forest Research Institute (KFRI) prepares LULUCF section of National Communication and provides the statistics on greenhouse gas emissions and removals associated with LULUCF activities. The information on this part is important for this study because it determines the quantity of carbon stored in unit area which will be, in turn, put into the simulation to compute the costs of carbon sink program. Therefore, a special care should be given to the assumptions made in computing the statistics on greenhouse gas emissions and removals associated with LULUCF activities.
Chapter 3. Methodology for Estimating the Costs of Carbon-Sink

In this chapter, we describe the econometric land use model considered and examine the required data to estimate the model based on the literature review. In addition, we illustrate the simulation procedures to estimate the costs of carbon-sink program.

1. Land Use Model

Theoretical basis for an econometric land use model is rent maximization. Barlow (1978) defines “land rent” as residual economic surplus; i.e., the total revenue less the total variable cost. The initial formulation of the concept of land rent is attributable to Ricardo (1817): “Rent is that portion of the produce of the earth, which is paid to the landlord or the use of the original and indestructible powers of the soils.” Ricardo introduced the notion that land rent is a function of soil fertility or climate.

Later, von Thünen extended Ricardo’s theory by adding location and transportation cost components to the model. Modern land use theory has been built on the early contributions of Ricardo and von Thünen and can be summarized as follows: Given a fixed land base, relative land rents are the key determinants of the allocation of land among competing uses. A recent addition to land use theory is the realization that heterogeneous land quality is crucial to determining the alternative uses of land.

Studies by Lichtenberg (1989) and Stavins and Jaffe (1990) demonstrate that existing aggregate land use allocations are strongly dependent on the characteristics of land. Importance of including land quality into a model for explaining current allocations has been proven through recent empirical analyses (Wu and Segerson (1995); Hardie and Parks (1997); Plantinga et al. (1999)).

A standard land use share model is considered in this study. The formulation of the model begins with the landowner’s problem of allocating a fixed amount of land to alternative uses. The solution to the landowner’s optimization problem yields an expression for the
maximum discounted profits from each parcel of land. The profit
expressions are incorporated into a second optimization problem that
solves for the optimal shares of total land allocated to each use. The
resulting optimal share equations are aggregated to yield an econometric
model that can be estimated with available data.

To state formally, we follow Miller and Plantinga (1999) and Ahn et al.
(2000) and assume a price-taking risk-neutral landowner who maximizes
profits by allocating a parcel of land to alternative uses. That is landowner
\( n_i (n_i = 1, \ldots, N_i) \) in a region \( i (i = 1, \ldots, I) \) is assumed to
maximize expected profits from use \( k (k = 1, \ldots, K) \) on land of quality
\( j (j = 1, \ldots, J) \).

For each land quality type, the land manager selects the area of land
allocated to each use \( h_{jk} (t, n_i) \geq 0 \) to maximize total restricted profits:

\[
\max \sum_k \pi_k (x(t, n_i), h_{jk} ((t, n_i), n_i)) \quad \text{(1)}
\]

subject to
\[
\sum_k h_{jk} (t, n_i) = H_j (t, n_i) \quad \text{(2)}
\]

where \( x(t, n_i) \) is a vector of exogenous variables
\( h_{jk} (t, n_i) \) is the land area with quality \( j \) allocated to use \( k \)
\( H_j (t, n_i) \) is the total available land area with quality \( j \)

The Kuhn-Tucker solution to equation (1) is the optimal allocations
\( h_{jk} (x(t, n_i), H_j (t, n_i), n_i) \), and the optimal share of total land \( H_j (t, n_i) \)
allocated to use \( k \) is:

\[
f_k (x(t, n_i), t, n_i) = \frac{1}{H(t, n_i)} \sum_j h_{jk} (x(t, n_i), H_j (t, n_i), n_i) \quad \text{(3)}
\]

The static model in (1) is an appropriate description of land use
decision such as crop choice in which profits are realized at the end of
the period and the identical problem is repeated in subsequent periods.
When returns to alternative uses are realized many periods after the
allocation decision such as in forestry production, the problem should be
re-formulated in dynamic framework.
In dynamic framework, most analyses assume that a landowner allocates his/her parcel to maximize the expected present discounted values of profits. Plantinga (1996) proved that, under appropriate conditions, landowners would optimally allocate land to the use with the highest present profit values. In this case, optimal land use shares are defined by an expression similar to (3), but with $X(t, n_i)$ including discounted profits to alternative uses.

In practice, however, the optimal land use shares for individual landowner in (3) are most likely to be aggregated to be conformable with the available data. Data on acreage of land associated with individual landowner are difficult to obtain. A common form of data available is aggregate data by regions, and, thus, equation (3) should be aggregated over the individuals in the region.

We describe the procedure of model aggregation below. We begin by recognizing that, in practice, optimal shares may differ from actual shares due to exogenous shocks that occur after the land use decision is made. For instance, the ex post optimal share of forestland may be lower than the actual share if there are poor growing conditions or pest infestations. Therefore, the actual share of land allocated to use $k$ by landowner $n_i$ is:

$$s_{ik}(t, n_i) = f_{ik}(X(t, n_i), t, n_i) + u_{ik}(t, n_i)$$  \hspace{0.5cm} (4)

where $u_{ik}(t, n_i)$ are mean zero error terms. In addition, conditions that the actual and optimal shares sum to 1 leads to:

$$\sum_k u_{ik}(t, n_i) = 0$$  \hspace{0.5cm} (5)

Given the exogenous nature of the shocks, we assume they are uncorrelated with the explanatory variables:

$$E[X(t, n_i)u_{ik}(t, n_i)] = 0 \hspace{1cm} \text{for all } t, n_i, l, k.$$  \hspace{0.5cm} (6)

Most often times, aggregate measures of forest and agricultural land areas are compiled from area-frame surveys of individual allocation decisions and self-enumerated report. The observed share of land allocated to use $k$ in region $i$ may be assembled as:
\[
y_i(t,i) = \sum_{n=1}^{N_i} w(t,n_i) [s_i(t,n_i) + \nu_i(t,n_i)] + \psi(t)
= p_k(t,n_i) + \epsilon(t,i) \tag{7}
\]

If the data are based on an area-frame sample, \(w(t,n_i)\) represents the sample weight assigned to individual \(n_i\), \(\nu_i(t,n_i)\) is the potential sampling error associated with each observation, and \(\psi(t)\) is the aggregate sampling error. When the data are derived from a complete enumeration of the population, \(w(t,n_i)\) is relative share of land in region \(i\) held by landowner \(n_i\), and the error terms have a corresponding interpretation. We assume that the sampling errors have zero means, are correlated across uses by construction, and are uncorrelated with the explanatory variables.

We interpret \(p_k(t,i)\) as the expected share of land in region \(i\) allocated to use \(k\) at time \(t\). By substituting (4) into (7), we notice that the expected shares become a function of the full set of decision variables, \(X(t,n_i)\) for all \(n_i\). As with the land share data, individual-specific information on the decision variables is typically unavailable, and researchers commonly use regional-level averages. The regional average data is denoted \(X(t,i)\) and include proxy variables for the land quality characteristics of region \(i\). The composite error terms \(\epsilon(t,i)\) are assumed to have a mean-variance structure similar to the \(u_k(t,n_i)\).

In particular, region-specific decision variables are assumed to be uncorrelated with the aggregate errors in the observed land use shares:

\[
E[X(t,i)\epsilon(t,i)] = 0 \quad \text{for all } t, i, l, k. \tag{8}
\]

We follow earlier authors (Wu and Segerson (1995); Hardie and Parks (1997); Plantinga et al. (1999)) and specify the expected shares as a logistic function of the linear combination of decision variables and unknown parameters \(\beta_k\):

\[
p_k(t,i) = \frac{\exp(\beta_k X(t,i))}{\sum_{k=1}^{K} \exp(\beta_k X(t,i))} \tag{9}
\]

The logistic specification is convenient because it constraints the shares to the unit interval, and the transformation in Chapter 19 of Judge et al.
Methodology for Estimating the Costs of Carbon-Sink

(1988) yields a model linear in the parameters:

\[ \ln(y_n(t,i) / y_n(t,i)) = \beta X(t,i) - \beta X(t,i) + \tilde{\varepsilon} \]

where \( \tilde{\varepsilon} \) is the resulting error term. The model is identified if we constrain \( \beta_i = 0 \). Therefore, we estimate (10) which is the system of equations consisting of \( k-1 \) equations.

2. Determinants of Land Use and Data

According to the theory of land use dating back to Ricardo and von Thünen, a landowner allocates a parcel of land to the use providing the highest level of rent (or net economic returns). Throughout the previous empirical studies, the additional factors found to significantly affect land use allocation decisions are land productivity, location, and demographic characteristics.

This section describes how to measure the determinants of land use (i.e. the variables in \( X(t,i) \)) identified in the literature. This helps to understand the required data to construct each variable in the application of the model presented above to Korea. As indicated in the model illustration, the data for estimating typical land use share model is panel consisting of time-series and cross-sectional observations.

Land Use Shares

Forestland share is defined as the ratio of private timberland area to total land area in region \( i \) at time \( t \). Public forestland is excluded because the allocation of public land tends to depend on the factors other than market forces. Agricultural land share is usually defined as the sum of shares in cropland and pastureland. Urban land share is defined as the ratio of land in developed use to total land. In many empirical studies, however, urban land is often included in the residual category, which is defined as the share of total land in uses other than forestry and agriculture due to the lack of reliable data on urban land share over time.

Net Returns (or rent) from Forestland

In principle, net returns from private timberland in region \( i \) at time \( t \) are measured as the present discounted value of the infinite stream of
timber revenue less timber management costs per acre. In practice, however, the timber management cost is often ignored because intensively managed timberlands takes a negligible proportion of total timberland. Revenue streams are calculated separately for major forest types by using type-specific yield curves, rotation lengths, and stumpage prices. Finally, net returns for each region are computed as a weighted average of type-specific net returns, where the weights are based on the forest-type compositions.

Net Returns from Agricultural Land
Agricultural net returns in region \( i \) at time \( t \) are calculated as the real annual per-acre net returns from cropland and pastureland. Net returns for each region is a weighted average of revenues (price times yield) less variable production costs for major crops and pasture uses, where the weights correspond to crop and pasture shares of total agricultural land.

Population
In many empirical land use analyses, population measures are used to account for the allocation of land to the developed use. The most common form of population measure is the population density (total population in region \( i \) at time \( t \) divided by total land area). In some cases, the difference in population between \( t \) and \( t-1 \) is used instead.

Distance to the City
In addition to population, researchers employ the distance measure to explain the share of urban use. The rationale for including a distance measure is that lands closer to cities have more potential for conversion to developed uses. A distance to the city is typically computed as a distance from the center point of each region to the closest city using computer software.

Land Quality
In literature, land quality measures are included to control for the differences across the regions in land productivity. The land quality is determined depending on the various characteristics such as slope and permeability etc. and is commonly represented as index with discrete land classes. Either the average of land quality in a region or the proportion of land with high productivity, or both in some cases, is
included in the model estimation.

3. Simulation for Estimating the Costs of Carbon-Sink

Because the scope of this study does not include actual model estimation and simulation, we briefly explain the simulation procedure to estimate the costs of carbon-sink program in this section.

Estimates of the land use share model in (10) are the basis for the simulations of carbon sequestration programs. The basic approach is to simulate the effects of forest subsidies by increasing the forest rent variable. This implies increases in forest area and, in turn, increases in carbon sequestration. Each subsidy level is associated with a change in carbon stored, measured by the carbon flows following afforestation of agricultural land.

There can be many ways to design carbon-sink programs. Typical approach is to pay landowners to retire their land for a period of time. Land is enrolled for a period time, say 10 years, and landowners are required to convert their land to forest. Landowners receive fixed annual payments plus the cost of establishing trees on land at the beginning of the period. The payments to the landowner represent the opportunity cost of enrollment. For a range of payments, we simulate increases in forest area and calculate the total carbon sequestration costs as the present value of establishment costs and payments over the program period.

Following the procedure described above, we calculate the flows of carbon associated with land entering and leaving the program and, for each payment level, the total cost per ton of carbon sequestered.
Chapter 4. Feasibility for Estimating the Costs of Carbon-Sink

In the last chapter we introduced an econometric land use models and identified the variables commonly used in empirical studies. In this chapter we investigate the feasibility of applying the econometric land use model. We begin by describing the historical trends of land use in Korea, and next section reviews the data availability to construct the variables identified to estimate the model.

1. Historical Trends of Land Use in Korea

Table 4-1. Historical Trends of Land Use in Korea

<table>
<thead>
<tr>
<th>Year</th>
<th>Agricultural land</th>
<th>Forest</th>
<th>Other land</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>area</td>
<td>%</td>
<td>area</td>
</tr>
<tr>
<td>1992</td>
<td>2,069</td>
<td>20.8</td>
<td>6,464</td>
</tr>
<tr>
<td>1993</td>
<td>2,504</td>
<td>20.7</td>
<td>6,459</td>
</tr>
<tr>
<td>1994</td>
<td>2,033</td>
<td>20.5</td>
<td>6,456</td>
</tr>
<tr>
<td>1995</td>
<td>1,985</td>
<td>20.0</td>
<td>6,451</td>
</tr>
<tr>
<td>1996</td>
<td>1,945</td>
<td>19.6</td>
<td>6,448</td>
</tr>
<tr>
<td>1997</td>
<td>1,923</td>
<td>19.4</td>
<td>6,441</td>
</tr>
<tr>
<td>1998</td>
<td>1,910</td>
<td>19.2</td>
<td>6,436</td>
</tr>
<tr>
<td>1999</td>
<td>1,898</td>
<td>19.0</td>
<td>6,430</td>
</tr>
<tr>
<td>2000</td>
<td>1,889</td>
<td>18.9</td>
<td>6,422</td>
</tr>
<tr>
<td>2001</td>
<td>1,876</td>
<td>18.8</td>
<td>6,415</td>
</tr>
<tr>
<td>2002</td>
<td>1,862</td>
<td>18.6</td>
<td>6,411</td>
</tr>
</tbody>
</table>

Source: Agricultural and Forestry Statistical Yearbook (Ministry of Agriculture and Forestry); Yearbook of Forest Statistics (Korea Forest Service)

Table 4-2. Conversion of Agricultural Land

<table>
<thead>
<tr>
<th>Year</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>12,017</td>
<td>9,883</td>
<td>10,209</td>
<td>13,275</td>
<td>12,996</td>
</tr>
<tr>
<td>From Rice paddy</td>
<td>6,745</td>
<td>5,143</td>
<td>5,346</td>
<td>7,016</td>
<td>6,951</td>
</tr>
<tr>
<td>From upland</td>
<td>5,272</td>
<td>4,740</td>
<td>4,863</td>
<td>6,259</td>
<td>6,045</td>
</tr>
</tbody>
</table>

Source: Agricultural and Forestry Statistical Yearbook (Ministry of Agriculture and Forestry)
Table 4-3. Conversion of Forest Land

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>10,100</td>
<td>7,700</td>
<td>7,968</td>
<td>7,170</td>
<td>7,386</td>
</tr>
<tr>
<td>To agricultural use</td>
<td>1,215</td>
<td>1,370</td>
<td>1,679</td>
<td>1,345</td>
<td>925</td>
</tr>
<tr>
<td>To cropland</td>
<td>816</td>
<td>790</td>
<td>1,310</td>
<td>1,217</td>
<td>810</td>
</tr>
<tr>
<td>To pastureland</td>
<td>399</td>
<td>580</td>
<td>369</td>
<td>128</td>
<td>115</td>
</tr>
<tr>
<td>To non-agricultural use</td>
<td>8,885</td>
<td>6,330</td>
<td>6,289</td>
<td>5,825</td>
<td>6,461</td>
</tr>
</tbody>
</table>

Source: 2001 Major Statistics of Forestry (Korea Forest Service, 2002)

2. Data

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Chapter 5. Conclusion

The results of this study are summarized as follows. We find out that, in Korea, the researches on land use change and carbon-fixation capability are relatively well documented and the related data are well accumulated. The main source of information for this part is Korea Forest Research Institute (KFRI). KFRI prepares LULUCF section of National Communication and provides the statistics on greenhouse gas emissions and removals associated with LULUCF activities according to Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. The information on this part is important because it determines the quantity of carbon stored in unit area which will be, in turn, put into the simulation to compute the cost of carbon sink program. Therefore, a special care should be given to the assumptions made in computing the statistics on greenhouse gas emissions and removals associated with LULUCF activities.

An econometric land use model, typically, employs the panel data to reflect the temporal and spatial changes in land use patterns and recognizes relative rents among competing uses, land quality, population, distance to the city as the key factors that affect land use change. Constructing the key variables mentioned above in panel data format requires pre-determination on the units of time-series and cross-sectional data series. Based on the results of data review, we find that most data are collected in yearly basis; thus, it is reasonable to arrange the time-series observations annually. For the spatial unit, however, we realize that the coverage of available data varies. For instance, some data scale down only to broad administrative regions, and some data scale down further in detail. Important task in assembling panel data is maintaining the consistency of time-series and cross-sectional observation unit, and determining the appropriate cross-sectional unit needs a further consideration.

In conclusion, if we put aside the statistical significance of the model estimates, application of an econometric land use model to estimate the cost of carbon-sink program is feasible in Korea. The success of the subsequent study will depend on the quality of data and the flexibility and robustness of the model.
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