B-15.2.2 Collaborative Studies for Developing AIM/Impact Model - Development of Agricultural Impact Models (Final Report)

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Abstract: Recently, climate change impact on agriculture in the Asian-Pacific region is a matter of concern of policy-makers. To satisfy this urgent needs, we developed a long-term model of food demand and supply considering agriculture production and trade in the course of collaborative research with International Institute for Applied Systems Analysis (IIASA). The model consists of three parts: estimation of potential crop productivity under climate change (AEZ), simulation of global market equilibrium of agricultural and other good (BLS) and land-use change model. In this study, we constructed the basic structure of these models and executed some experiment using the models.

Key Words: Climate change impact, the Asian-Pacific region, Agricultural production, GIS, BLS, AEZ

1. Introduction and Research Objective

We developed a model which enables us to assess impacts of global warming, in the course of collaborative studies for developing integrated assessment model in the Asia-Pacific region (AIM). Since climate impacts on food production and land-use change are crucial in developing countries' economy, development of such kind of model is urgently required by developing countries in the Asia-Pacific region. There is a general equilibrium model of agricultural economics originally developed at IIASA (BLS), which can examine long-term (50 - 100 years) event such as climate change (Fischer et al., 1988). We judged that it would be the most efficient way to modify this model and apply the modified one to the objective area, the Asian-Pacific region, to respond to the urgent political needs in a short period.

The objective of this study is to develop a simulation model which evaluate climate impact on agriculture and landuse in the Asia-Pacific region under the collaborative research with IIASA (International Institute for Applied Systems Analysis). With the use of the model, we can estimate:

(1) How does direct impact on agriculture productivity affect on the amount of agricultural production in each country through an international market of agricultural and other commodities ?

(2) As a result of (1), how much will cultivated area and other land-use increase or decrease ?

2. Development of long-term assessment model of food demand and supply

2.1 The structure of the long-term model

In IIASA, a long-term model of food demand and supply is being developed in the joint research between methodology and decision making analysis project team (MDA) and Land-Use and Land-Cover change project team (LUC). The model developed in this study with the help of these project teams is for evaluating the secondary impact of climate change on agriculture. While the direct impact on agriculture (primary impact) can be estimated using AIM model, the direct impact can be adjusted through international market. For instance, agricultural productivity decrease in one country may cause the increase of production of agricultural commodity in other countries to satisfy the demand for export good. To project this secondary effect, development of the model in this study is required. Long-term model contains of the following three sub-models:

(a) Estimation of potential crop productivity under global warming (AEZ)
(b) Estimation of domestic agricultural production, cultivated area, prices, world trade (BLS)
(c) Estimation of spatial distribution of agricultural land and other land uses.

BLS, a long-term projection model of food demand and supply, was developed by Food and Agriculture Project (FAP) in IIASA. AEZ (FAO, 1978), a potential crop productivity model originally developed by FAO, is now under refinement by the joint research of FAO (Food and Agriculture Organization of United Nations) and IIASA. Land-use change model (Fischer, 1996a) is now under development between LUC project in IIASA and the center for world food study in Amsterdam Vrije University.

2.2 BLS

2.2.1 Basic structure

The BLS is a general equilibrium model system. This necessitates that all economic activities are represented in the model. Financial flows as well as commodity flows within a country and at the international level are consistent in the sense that they balance. Whatever is produced will be demanded, either for human consumption, feed or intermediate input; it might be traded or put into storage. Consistency of financial flows is imposed at the level of the economic agents in the model (individual income groups, governments, etc.), at the national as well as the international level. This implies that total expenditures cannot exceed total income from economic activities and from abroad in form of financial transfers, minus savings. On a global scale, not more can be spent than what is earned.

The country models are linked through trade, world market prices and financial flows. The system is solved in annual increments, simultaneously for all countries. It is assumed that supply does not adjust instantaneously to new economic conditions. Only supply that will be marketed in the following year is affected by possible changes in the economic environment. A first round of exports from all the countries is calculated for an initial set of world prices, and international market clearance is checked for each commodity. World prices are then revised, using an optimizing algorithm, and again transmitted to the national models. Next, these generate new domestic equilibria and adjust net exports. This process is repeated until the world markets are cleared in all commodities. At each stage of the iteration the domestic markets are in equilibrium. Since these steps are taken on a year-by-year basis, a recursive dynamic simulation results.

The concept of an economic agent who decides on production and disappearance is the basis on which the BLS is built. Producers maximize returns to primary factors they are endowed with in their production activities. Consumers are assumed to maximize utility. And governments follow prescribed objectives in their policy setting within the constraints on balancing expenditures with the revenues generated through taxes, tariffs or other means, and international transfers.

Although the BLS contains different types of models, all adhere to some common specifications. The models contain two main sectors: agriculture and non-agriculture. Agriculture produces nine aggregated commodities, all non-agricultural activities are combined into one single aggregate. Production is critically dependent on the availability of the primary production factors land, labor and capital. The former is used only in the agricultural sector, while the latter two are determinants of output in both the agricultural and the non-agricultural sectors.

2.3 AEZ

2.3.1 Basic structure of AEZ

These ten years, the joint research project between FAO and IIASA extended the AEZ model, which estimates potential crop productivity of 11 crops from natural resource environment: 24-hour average temperature, average daytime temperature, precipitation, photosynthetically active radiation, potential evapotranspiration, chemical and physical soil properties, and slope. The 11 crops are the most important 11 crops judged from statistical food production and supply data: wheat, rice, maize, millet, sorghum, soybeans, cotton, phaseolus beans, white potato, sweet potato and cassava. Along with parameters prepared for each crop, grow of biomass is simulated biophysically. In agriculture-landuse model, this AEZ model is used to estimate parameters of production functions.

2.3.2 Expansion of AEZ model

To be used as a production function of BLS, which estimates impacts on both domestic and global agricultural market, or of the agriculture-landuse model, which estimates land-use change under environmental changes, however, the following additive expansion would be required.
(a) To prepare growth parameters of less important crops.
(b) To include a direct effect of CO2 concentration (CO2 fertilization).
In this collaborative study, we developed an expanded AEZ which considers the above two points.

2.3.2.1 Additional objective crops

Adding to the model parameters of original 11 crops, we are now collecting parameters for extra crops. The parameters we are collecting are type of photosynthesis path, normal growing period, normal yield formation period, maximum leaf area index and harvest index. Objective crops are more detailed division of rice varieties (Japonica and Indica), foxtail millet, rye, chick pea, cow pea, rape, groundnut, oil palm, sunflower, olive, sugarcane, sugar beet, banana and alfalfa.

2.3.2.2 Introduction of the direct effect of CO2 concentration

CO2 fertilization is a composition of two processes caused by increase of atmospheric CO2. The one is the increased efficiency of photosynthesis because of photorespiration and the other process is the increased water use efficiency because of the closure of stomata.

In the process of photosynthesis, carbon dioxide and water are combined in plant leaves utilizing sunlight to produce carbohydrates and oxygen. Plants differ in what kind of intermediate steps and compounds are produced in the photosynthetic process. One major group of plants is referred to as C3 plants because of one of the first intermediate compounds has three carbon atoms (phosphoglyceric acid). Most agricultural crops, notably wheat, rice, barley, soybeans and potatoes, belong to the C3 group. Similarly, a second group of plants , termed C4 plants, produces a compound with four carbon atoms (oxaloacetic acid). C4 plants of economic importance include maize, sorghum, millet, and sugarcane.

Plant species vary in their response to CO2 in part because of these differing photosynthetic mechanisms. C3 plants use up some of the solar energy they absorb in a process known as photorespiration. In this process, which occurs only in the light, a considerable fraction of the carbon initially reduced from CO2 and fixed into carbohydrates is re-oxidized to CO2, reducing the net amount of carbohydrates being accumulated. C3 species tend to respond readily to increased CO2 levels because photorespiration is suppressed in these conditions. In C4 plants, on the other hand, CO2 is trapped inside the leaf and then concentrated in the cells which carry on photosynthesis. These plants are photosynthetically more efficient than C3 plants under present CO2 levels, but have been found to be less responsive to CO2 enrichment.

Stomata is the small openings in leaf surfaces through which CO2 is absorbed and water vapor released. Accordingly, a rise in atmospheric CO2 may improve water-use efficiency. Thus, by itself, increased CO2 can increase yield and reduce water use per unit of biomass.

Cure et al. (1986) surveyed the difference of yield of some crops per acre (%) between 340ppm CO2 and 680ppm CO2. In our study, the result of potential productivity model is modified using Cure's value as the rate of change of potential productivity under the increased atmospheric CO2. We assumed that CO2 fertilization effect respond rationally to the increased CO2 concentration from 340ppm at CO2 concentration between 340ppm and 680ppm, then potential productivity considering CO2 fertilization in object year t, y_t (kg/ha), is calculated as follows.

$$y_t(x, Y_t) = Y_t \times \left\{ 1 + \frac{f_{680}}{100} \left(\frac{x}{340} - 1 \right) \right\} \quad . \quad (1)$$

Here, x(ppm) is atmospheric CO2 in the year t, Y_t (kg/ha) is the potential productivity without considering CO2 fertilization (output of original AEZ model), and f_{680} (%) is the difference ratio of potential crop productivity between 340ppm and 680ppm.

2.4 Development of basic structure of landuse change model

Climate change impact on crop productivity causes land-use change. To simulate this process quantitatively and spatially, we are developing land-use change model. Developed land-use model simulate the process that human causes land-use change through economic activity. This model is aimed at the analysis of spatial and intertemporal interactions among various socioeconomic and biogeophysical factors that drive land-use change. Exact prediction of such complex systems over medium and long time-horizons is impossible. Instead, we emphasize the role of comparative studies of the impacts from various demographic, economic and political factors on the dynamics of land-use change. Taking this into account, a model specification where policies and decisions of economic agents are explicitly introduced becomes essential.

Economic activity is illustrated by general equilibrium model, and land-use is estimated as a result of the distribution problem of limited land resources (maximization of social welfare). To decide distribution of resources, equity between generations as well as equity among regions must be considered explicitly. Or not, people in some region might be forced to experience poverty without sufficient resources, or future generation might be deprived.

Figure 1 illustrates the framework of developed land-use model. Trajectories of variables which are not dealt with inside the land-use model, but that are important to the decisions of land-managers, including policiy-formulation and technological development, are incorporated as scenarios. As for demography and economic development, the outputs of existing studies (ex. World Bank Projection) are used. Climate change is produced by AIM/Climate model which utilizes GCM outputs distributed by other climate research project.

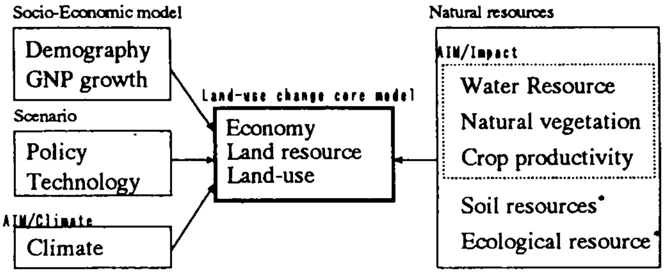

Figure 1 Basic structure of Land-use change model. (* denotes pre-development.)

Concerned with natural resources surrounding land-use, GIS-based AIM/Impact model can help natural scientific analysis of natural vegetation, agricultural productivity and water resource. These analysis are aggregated into appropriate region level, which are used as input data or parameters in the main land resource-economy-landuse model.

The core model, land resource-economy-landuse model, is developed with GAMS, which is a non linear modeling language run on MSDOS or UNIX. This model is theoretically built to be capable of treating trade barrier, imperfect competition and generation problem so as to illustrate the actual world realistically. However, because of the data availability for parameter estimation or difficulty of solution, some factors are assumed to be given as a scenario, and moreover some could not be illustrated on the model program.

3. Conclusion

To evaluate the climate impact on agriculture comprehensively, refinement of the existing crop productivity model, implementation of agricultural general equilibrium model which considers world trade, development of landuse model which simulate landuse change caused by human activity. The major findings are listed below.

1. Adding to the model parameters of original 11 crops treated in AEZ, we are now collecting parameters for extra crops. This makes analysis of adaptation more realistic.
2. The direct effect of atmospheric CO2 is introduced into crop productivity model.
3. Economic impact on agriculture of climate change is estimated using BLS. The result was compared using the macro index such as GDP of agricultural commodities. It was found that negative impact of climate change is mitigated largely by CO2 fertilization both in developed countries and in developing countries. However, damage in developing countries tends to be more serious than in developed countries even considering CO2 fertilization.
4. Formulation of land-use model: With non-linear model program, prototype model is written.

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