Chapter 3 The CGELUC Model and Its Application

The structure of regional land use is influenced by socioeconomic factors, including industrial structure, trade environment, economic policies and institutional arrangements. These multi-dimensional factors should be taken into consideration by different departments as part of an open, balanced economic system. The model of Computable General Equilibrium of Land Use Change (CGELUC) uses the framework of the Computable General Equilibrium (CGE) to analyze the factors that influence regional land use types. The analysis is based on macroscopic quantitative analysis and reveals relationships among the land use structure of cultivated land, economic forest[①], meadow for grazing, and economic development. The CGELUC model constructs a mechanism-based model to analyze dynamic laws of evolving land use structure at regional scales. The CGE model is applicable to policy the analysis associated with economic activities (Armington; 1969; Dixon et al., 1984; Conrad, 2001; Gelan, 2002; Liu et al., 2003). Economic activities are the main driving force behind structural changes in land use and are also constrained by the structure of regional land use (Rozelle and Rosegrant, 1997; Krausmann et al., 2003; Veldkamp and Verburg, 2004; Conway and Lathrop, 2005). Therefore, a solid theoretical basis exists for using the CGE model to simulate structural changes in regional land use (Fu et al., 1999; Böhringer and Löschel, 2006; Deng et al., 2010a). The CGELUC model uses the CGE model to study structural changes in regional land use based to some extent on computable general equilibrium ideas.

3.1 The CGELUC Model

Generally, the CGELUC model is divided into two parts when simulating structural changes in regional land use, including a thematic quantitative

① Economic forest and meadow for grazing are closely related to industrial production and livestock production that directly indicate economic values. In the CGELUC model, the equilibrium among cultivated land, economic forest, meadow for grazing are simulated according to the CGE modeling approach. Apart from cultivated land, economic forest and meadow for grazing, the public welfare forest and grassland cover, together with water, built-up area and unused land, are predicted based on econometric models, which differ from CGE modeling.

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analysis section and an equilibrium analysis section of regional land area supply and demand. The two parts are linked by feedbacks from a series of relevant parameters. The thematic quantitative analysis is used to analyze the unsolvable relationships between industrial development and area changes in developed regions of water, grassland, woodland and unused land. These are then put into the equilibrium analysis section, in which supply and demand of regional land areas are input as exogenous variables. The changing processes and driving mechanisms of these types of land use are difficult to describe with general formulas, while cultivated land, economic forest and grassland[1] are closely associated with economic development. Economic activity related to social demand is the main factor driving structural changes in three types of land use and is also constrained by the structure of regional land use. The equilibrium analysis section of regional land use structure mainly simulates the relationship between land use structure and economic activities (Deng et al., 2010a).

The thematic quantitative analysis is mainly used to simulate and predict total changes in developed regions of water, grassland, woodland and unused land. Changes in these land use areas are then exported under specific scenarios to the equilibrium analysis section of land area supply and demand, and the influence of exogenous factors (such as land policy and planning) on regional land use structure is then analyzed. The equilibrium analysis section of land area supply and demand calculates changes in cultivated land, economic forest and grassland areas, and these calculated parameters of regional land use structure can then serve to spatially allocate land use change at the simulated grid scale. Macroeconomic variables such as production volume, price index and land rent are used as land policy parameters, and the total economic output, employment rate and energy consumption are used as characteristic variables that indicate industrial development of land-consumption sectors (Haberl et al., 2001; Lambin et al., 2001). Analysis of the influence of land policies can be used to make corresponding baseline hypotheses and calculations according to the current amount of land use and land use characteristics. The analysis is based on results of government investments, technical progress of sectors consuming land, structural changes in product consumption. The impacts of macroeconomic policies on the economic variables are then included in the equilibrium analysis section of land area supply and demand (Lehtonen et al., 2005; Leip et al., 2008). This section estimates and quantifies product demand, economic development and land use efficiency. The regional quantitative analysis section further corrects the parameters based on feedback of the modules mentioned above. The process above cycles is deducted through a number of iterations and restricted by the total amount of land use area until it reaches a balance between supply and demand of areas with types of different land use types among regional sectors.

Land plays a key role in the CGELUC model. On one hand, land is involved in production activities and is traded in the factor market as a commodity. Alternatively, land uses change with changing human activities, such as farmland returning to forest or grassland, reclaiming wasteland and clearing forest for farmland expansion. The change in land property is generally called land use conversion (Deng et al., 2008).

The computer-based CGELUC model is constructed based on the CGE theory, the areas of five land use types and the connections between economic development and land use structure of developed areas of economic forest and grassland. It consists of production, demand, price, trade, income distribution and macroeconomic closure modules. On one hand, all input land, or land associated with various types of production activities, will receive an income from rent. On the other hand, the socioeconomic benefits of different land use types differ, and this external difference drives conversion among land use types that requires capital. Finally, agricultural, forest and livestock products produced directly on the land are land output products, while other products are non-land output products. The difference between the two is that the land with non-land output products is considered as an input factor, and the land with land output products is considered as a commodity. Here, the module equations associated with land use structure are highlighted, and other equations are similar to the equation of the CGE model. The following sections of this chapter will use factor inputs and land conversion in the process of commodity production as an example (the production structure of the CGELUC model is shown in Fig. 3.1) to introduce the relationship between variables in the thematic quantitative analysis section. An emphasis is placed on the quantitative expression of the relationship between the land and its socioeconomic variables.

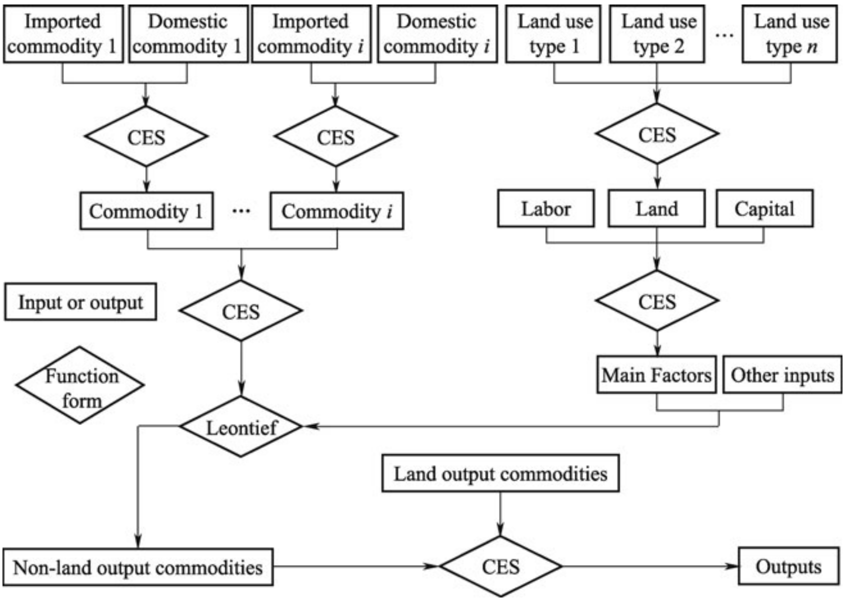

Fig. 3.1 Rationale of the CGELUC model.

3.1.1 Framework of the CGELUC Model

CGELUC models vary in complexity and size; their scope can be as large as the world or as small as a town. The model complexity is mainly described by studying the number and behavior of objects in the economic system. For example, a description of government expenditure based on a budget is far simpler than actual government consumption behavior. In addition, government consumption behavior is also constrained by the development of the whole economy, institutional reform and advancement of social welfare in the practical operation of the economy. The size of the model is based on the "small country hypothesis" on whether the economy involved is world-wide or in a town. The CGELUC model differs from empirical statistical models because it is a mechanistic model based on microeconomic theory and can effectively reflect mechanisms in structural changes in regional land use.

3.1.1.1 Model Features

One developing trend in the CGELUC model is to make the model more delicate and complex, including finer divisions of the model's sectors, wider classifications of consumers and non-recursive dynamics of the model. The other trend is to make the model more suited for analysis of economic and structural changes in regional land use by combining more practical characteristics of the economy. These include accounting for imperfect competition, technological progress and institutional factors endogenously in the model. The CGELUC model retains three main features of the traditional CGE model:

- The number of commodities and factors and the relative prices are decided by the endogenous model;
- The model can calculate the numerical solution of the prices of commodities and factor prices when they are entirely removed;
- Despite having multiple sections, the model's description of the whole system is still highly general (Wong and Alavalapati, 2003). Because of needs for simulating and analyzing land system dynamics, this book describes the CGELUC model as a multi-economic, multi-numeric market model that simulates optimized behavior based on relevant information.

The CGELUC model has significant benefits and unique characteristics for simulating land use conversion. First, it is an econometric model that systematically combines the mechanism-based CGE model with traditional empirical statistics. Its statistical mechanism emphasizes the area demand for regional land use types that cannot be revealed at the commodity level. Derivation of the theoretical mechanism model directly links with structural changes in cultivated land, economic forest and grassland related to commodity output. The CGELUC model integrates the behavior of microscopic subjects into the model system framework, which produces model explanations for results that have a reasonable theoretical basis. Second, the CGELUC model shows effects of market mechanisms. It introduces a price adjustment mechanism, replaces a linear function in the traditional model with a non-linear function and describes the response of the land use structure to disturbances, such as external policy and trade. Finally, an interaction and volatility transmission mechanism exists within the CGELUC model, i.e., if any part of the model suffers an external disturbance, the influence will be transmitted to land use linked with decision-making and behavior of the subjects of the whole economic system and lead to regional land use conversion. This process reflects the "general equilibrium" feature of the CGELUC model where a slight move in one part may affect the entire system.

3.1.1.2 Model Composition

The primary objective of the regional equilibrium development analysis module of the CGELUC model is to characterize the behavior of pursuing maximum profit or the effects of subjects within respective budgets that lead to structural changes in regional land use and to determine how this behavior leads to such changes. The macroeconometric model can be used to determine input parameters for simulation and analysis to maintain a balance in the total amount of regional land. The most basic CGE model includes three sets of equations that represent supply, demand and the balance between supply and demand (Gelan, 2002). We can view them from the basic framework of the CGELUC model (Fig. 3.2).

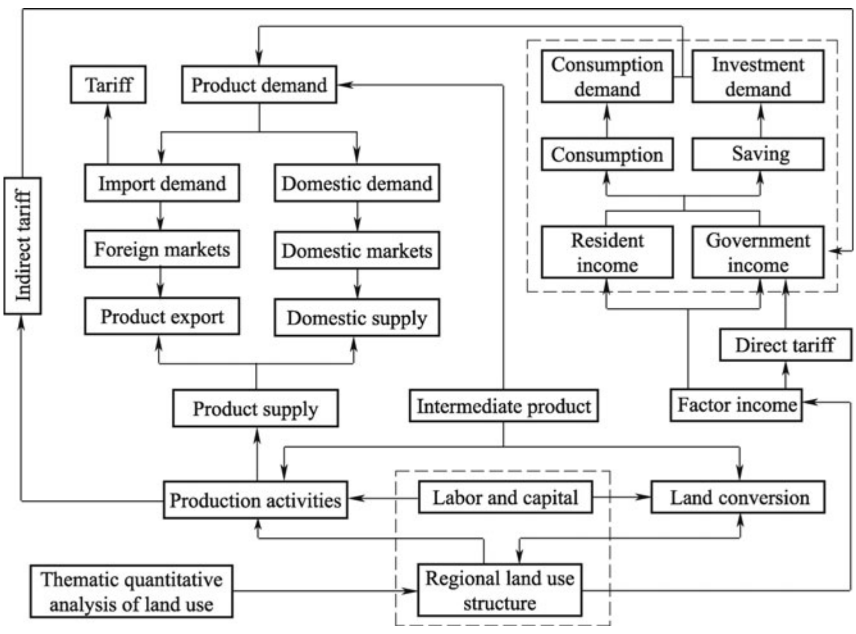

Fig. 3.2 Elements included in the CGELUC model.

It is generally necessary to add more economic subjects or to divide the model more precisely in accordance with different research needs in the simulated regional land use structure. In this book, the CGELUC model is divided into thematic quantitative analysis, production behavior, land use conversion, consumption behavior, government action, foreign trade, market equilibrium and macroscopic closure.

Thematic quantitative analysis

The CGELUC model describes the relationships among land desertification, changes in water area and expansion of developed area and the factors that influence quantitative analysis. The dynamics of land system change, desertification and changes in water area, grassland excluding pasture grassland and forest excluding economic forest are mainly influenced by natural processes (Hietel et al., 2004). The developed areas are significantly influenced by population, economic aggregation and technical progress, generally change directionally and are highly suitable for simulation and estimation with econometric methods.

Production behavior

The CGELUC model characterizes production behavior with a quantitative description of the supply of products related to regional land use conversion and includes two types of equations: descriptive production equations and producer optimization equations. The common forms of descriptive production equations include the Cobb-Douglas function, constant elasticity of substitution (CES) function and two-tier or multi-tier nested CES function. The quantitative relationships among the production factor inputs, intermediate inputs and outputs can be described with these equations. Different production functions are generally chosen according to different research purposes for practical applications. The aim of the producer optimization equation or profit maximization equation is to define producer behavior, determine producer demand for various factors by making marginal returns of factors equal to their corresponding marginal productivity and describe how producers pursue minimum costs or maximum profits under constraint of the production function.

Land use conversion

In the CGELUC model, land use conversion requires investments of capital, labor, land and intermediate inputs, which are considered to be production behavior. Two types of equations characterize land use conversion: descriptive production equations and producer optimization equations. The descriptive production equations include the Cobb-Douglas function, the CES function and the two-tier or multi-tier nested CES function, which are used to describe the quantitative relationships among production factor inputs, intermediate inputs and outputs (Rozlle and Rosegrant, 1997; Hanasaki et al., 2008). Different land use conversion functions are generally chosen based on different research purposes and study areas. The land use conversion optimization equation aims to determine demands of producers for various factors by making marginal returns of various factors equal to their corresponding marginal conversion rates.

Consumption behavior

The CGELUC model characterizes consumption behavior mainly with descriptive equations and demands for relevant products of regional land use conversion, which includes the descriptive production equation and the consumer optimization equation. The descriptive production equation is mainly used to describe the constraints on consumers' budgets, i.e., the income and disposable income of consumers. The consumers' utility optimization equation is mainly used to describe the behavior of consumer's utility maximization, which includes the Cobb-Douglas function, the CES function and the Stone-Geary utility function. This type of equation aims to describe the behavior of consumers' pursuits of individual utility maximization under the constraint of a consumption budget.

Government behavior

Policy behavior such as government revenue, interest rates and subsidies is added to the model equation system only as exogenous variables in the CGELUC model. When the government changes its policy, i.e., when these control variables change, the changes influence the entire economic system. Government behavior in the CGELUC model is not limited to formulating relevant policies; more importantly, the government also acts as a consumer in the CGELUC model.

Foreign trade

The CGELUC model involves foreign trade as an important component to more accurately describe the system. The CGELUC model uses the small country assumption, i.e., imports and exports in the study area will not affect the stability of the world price. This assumption helps to describe the issues conveniently, but the complexity of the equation caused by involvement of foreign trade still cannot be avoided. For example, the model not only requires exports to be distinguished from commodities from a production aspect, but also requires imported commodities to be distinguished from domestic commodities from a consumption aspect. A common approach is to assume that domestic commodities and imported commodities are not completely replaceable and to describe the behavior of imports with CES equations and the behavior of exports with the constant elasticity of transformation equation.

Market equilibrium

Equilibrium is the core of the CGELUC model and mainly includes market equilibrium and the balance between income and expenditures.

– Product market equilibrium

Product market equilibrium requires that the total supply of products equals the total demand for products, i.e., equilibrium is achieved between production and consumption.

– Capital market equilibrium

Capital market equilibrium means that total investment equals total savings. If investments and savings are unbalanced, then corrections will be made through selling bonds, introducing foreign capital or changing the government's fiscal reserves.

– Factor market equilibrium

Factor market equilibrium mainly refers to equilibrium between supply and demand of labor and land market equilibrium. The factors flow between different departments due to differences in marginal benefits to achieve producer and consumer optimization.

– Residents' income and expenditure equilibrium

Residents' income and expenditure equilibrium means that residents spend all income, such as payments for labor and net foreign remittance, after paying individual income tax on consumption and savings.

– Government budget equilibrium

The government budget equilibrium is a generalized equilibrium. If government expenditures do not equal income, then a fiscal deficit will be added to government revenue as a variable so that the disequilibrium of the government budget can be expressed with a set of equations.

– International income and expenditure equilibrium

If a trade surplus or deficit exists, the net inflow of foreign capital is taken as the variable, i.e., international income and expenses should also maintain equilibrium.

Macroscopic closure

The different variables under various equilibrium conditions in the CGELUC model, e.g., changes in inventory, unemployment, surplus and deficit, provide an important way to study the actual state of disequilibrium. However, it is unrealistic to assume that the market, income and expenditures of various departments can simultaneously balance; only a conditional equilibrium can be achieved. Generally, four programs can be used to solve the problems above in the macroscopic closure theory of the CGELUC model, and different solutions are the main differences between different CGE schools of thought:

– Keynes formula: Forfeit the requirement that labor and commodity markets achieve equilibrium simultaneously. Take the employment rate as an endogenous variable, i.e., surplus labor is adequate in the whole system and can meet the demand for labor in the production sectors at any time. This reflects Keynes' assumption of deficient demand and surplus supply (Johanson, 1960).

– Kim Hansen formula: Consider government expenditures to be an endogenous variable and the total investment level to be an exogenous variable, maintaining maximum producer profits (Scarf and Hansen, 1973).

– Koldorian formula: Forfeit optimal conditions of production factors and consider the investment level and the government expenditure level as exogenous variables (Adelman and Robinson, 1978).

– Neoclassical formula: Consider the government expenditure level as an exogenous variable and the investment level as an endogenous variable to maintain the optimal conditions for producer profits. The total investment level will then be automatically adjusted to the savings level (Dervis, 1975).

The macroscopic closure theory of the CGELUC model makes trade-offs among the labor market, government budget and investment-saving equilibriums and optimal conditions for production.

3.1.2 Modules of the CGELUC Model

The CGELUC model can be divided into eight modules, i.e., the quantitative analysis module, production module, land use conversion module, product demand module, price module, income distribution module, saving-investment module, foreign trade module and equilibrium closure module.

3.1.2.1 Quantitative Analysis Module

The areas of developed regions, unused land, water, grassland with indirect economic value such as ungrazed or commonwealth grassland and forest with indirect economic value such as ecological commonwealth forest are simulated with the macroscopic econometric model.

Spatially lagged model

The spatially lagged model mainly explores whether the influence of variables is spatially diffuse (Irwin and Geoghegan, 2001; Verburg and Veldkamp, 2001). It is expressed as:

$$Y = \rho WY + X\beta + \varepsilon \tag{3.1}$$

where Y is a dependent variable, which is the area of the land use types mentioned above; X is an explanatory variable to represent the factors that cause changes in the area of the land use types mentioned above; ρ is the spatial correlation coefficient; W is the spatial weight matrix; WY is a spatially lagged dependent variable; ε is the random error term.

Spatial error model

The spatial error model is used to measure the degree of spatial influence of the dependent variable. Its mathematical expression is:

$$\begin{aligned} Y &= X\beta + \varepsilon \\ \varepsilon &= \lambda W\varepsilon + \mu \end{aligned} \tag{3.2}$$

where Y is the dependent variable, which is the area of land use types mentioned above; X is an explanatory variable representing the factors that cause changes in the area of land use types mentioned above; ε is a random error term; λ is spatial error coefficient of the cross-section dependent vector; W is the spatial weight matrix and μ is the vector of random error with normal distribution.

3.1.2.2 Product Production Module

Production of final products

$$Z_c(t) = \min_{d,l} \left\{ \frac{X_{d,c}(t)}{ax_{d,c}(t)}, \frac{LK_{l,c}(t)}{al_{l,c}(t)}, \frac{Y_c(t)}{ay_c(t)} \right\} \tag{3.3}$$

where $Z_c(t)$ represents the amount of final products produced in the tth year; $X_{d,c}(t)$ is the amount of the intermediate product d consumed in the production process of the final product c; $ax_{d,c}(t)$ stands for the consumption coefficient of the intermediate product d in the production process of the final product c; $LK_{l,c}(t)$ represents the amount of the lth type of land consumed in the production process of the product c; $al_{l,c}(t)$ is the consumption coefficient of the l types of land in the production process of the final product c; $Y_c(t)$ signifies the amount of intermediate products consumed in the production process of the final product c; $ay_c(t)$ represents the consumption coefficient of the intermediate products in the production process of the final product c.

When production is optimized, there must be:

$$\begin{cases} Y_c(t) = ay_c(t) Z_c(t) \\ X_{d,c}(t) = ax_{d,c}(t) Z_c(t) \\ LK_{l,c}(t) = al_{l,c}(t) Z_c(t) \end{cases} \tag{3.4}$$

Intermediate product production

$$Y_c(t) = b_c(t) \prod_f Fc_{f,c}(t)^{\beta_{f,c}(t)} \tag{3.5}$$

where $b_c(t)$ represents the production scale coefficient of the intermediate product c; $Fc_{f,c}(t)$ is the number of the input factor f in the production process of the intermediate product c; $\beta_{f,c}(t)$ is the share of factor f in the production process of the intermediate product c.

Integrated products for home sale

$$Q_c(t) = \gamma_c(t) \left(\delta m_c(t) M_c(t)^{\eta_c(t)} + \delta d_c(t) DK_c(t)^{\eta_c(t)} \right)^{1/\eta_c(t)} \tag{3.6}$$

where $Q_c(t)$ is the number of integrated products sold at home in the tth year; $\delta m_c(t)$ stands for the proportion of imported products in the integrated products sold at home; $M_c(t)$ is the number of imports; $\delta d_c(t)$ stands for the proportion of locally produced products in the integrated products sold at home; $DK_c(t)$ is the number of products that are locally produced and sold; $\gamma_c(t)$ represents the scale parameters of the Armington function; $\eta_c(t)$ is the elasticity of substitution between the local product c and the imported product c.

Number of products locally produced and sold

$$DK_c\left(t\right)=\left(\frac{\gamma_c\left(t\right)^{\eta_c(t)}\,\delta d_c\left(t\right)Pq_c\left(t\right)}{Pd_c\left(t\right)}\right)^{1/(1-\eta_c(t))}Q_c\left(t\right) \quad (3.7)$$

where $Pq_c(t)$ represents the price of the integrated product c sold at home; $Pd_c(t)$ is the domestic selling price of the domestic product c.

Total quantity of domestic products

$$Z_c\left(t\right)=\theta_c\left(t\right)\left(\xi e_c\left(t\right)EK_c\left(t\right)^{\Phi_c(t)}+\xi d_c\left(t\right)DK_c\left(t\right)^{\Phi_c(t)}\right)^{1/\Phi_c(t)} \quad (3.8)$$

where $\theta_c(t)$ represents the scale parameters of the transfer function; $\xi e_c(t)$ is the share parameter of the export c in the conversion function; $\xi d_c(t)$ is the share parameter of the product c produced and sold at home in the conversion function; $EK_c(t)$ stands for the quantity of the export c; $\Phi_c(t)$ is the elasticity of substitution between the product c produced and sold at home and the export c.

Quantity of products locally produced and sold

$$DK_c\left(t\right)=\left(\frac{\theta_c\left(t\right)^{\Phi_c(t)}\,\xi d_c\left(t\right)\left(1+\tau_c\left(t\right)\right)Ps_c\left(t\right)}{Pd_c\left(t\right)}\right)^{1/(1-\Phi_c(t))}Z_c\left(t\right) \quad (3.9)$$

where $\tau_c(t)$ is the indirect tax rate of the product c; $Ps_c(t)$ represents the domestic price of supply of the domestic product c.

3.1.2.3 Land Use Conversion Module

Land use conversion

$$Dl_{zl}\left(t\right)=\min\left\{\frac{Xl_{c,zl}\left(t\right)}{axl_{c,zl}\left(t\right)},\ \sum_l Fl_{l,zl}\left(t\right),\ \frac{Yl_{zl}\left(t\right)}{ayl_{zl}\left(t\right)}\right\} \quad (3.10)$$

where $Dl_{zl}(t)$ is the amount of the zlth newly-increased land in the tth year; $Xl_{c,zl}(t)$ stands for the amount of intermediate input c consumed in the zlth land use conversion process; $axl_{c,zl}(t)$ is the consumption coefficient of the intermediate input c in the zlth land use conversion process; $Fl_{l,zl}(t)$ is the area of the lth land input into the zlth land use conversion process; $Yl_{zl}(t)$ represents the quantity of intermediate products consumed in the zlth land use conversion process; $ayl_{zl}(t)$ stands for the consumption coefficients of the intermediate products in the zlth land use conversion process.

When efficiency of the conversion reaches a peak, there must be:

$$\begin{cases} Yl_{zl}(t) = ayl_{zl}(t)\,Dl_{zl}(t) \\ Xl_{c,zl}(t) = axl_{c,zl}(t)\,Dl_{zl}(t) \\ Fl_{l,zl}(t) = \omega_{l,zl}(t)\,Dl_{zl}(t) \end{cases} \tag{3.11}$$

Production of intermediate products input into land use conversion

$$Yl_{zl}(t) = bl_{zl}(t) \prod_f Fll_{f,zl}(t)^{\beta l_{f,zl}(t)} \tag{3.12}$$

where $bl_{zl}(t)$ is the scale parameter of the production function of the intermediate product input into the zlth land use conversion; $Fll_{f,zl}(t)$ stands for the amount of factor f input into the production of intermediate products of the zlth land use conversion; $\beta l_{f,zl}(t)$ stands for the share of factor f in the production of intermediate products of the zlth land use conversion.

*Amount of various land use types in the (t+1)*th *year*

$$FFl_l(t+1) = FFl_l(t) + Dl_{zl}(t) - \sum_{zk} Fl_{l,zk}(t) \tag{3.13}$$

where $FFl_l(t)$ is the amount of the lth land use type in the tth year.

3.1.2.4 Product Demand Module

Intermediate input

$$Xc_c(t) = \sum_d X_{c,d}(t) + \sum_{zl} Xl_{c,zl}(t) \tag{3.14}$$

where $Xc_c(t)$ is the total demand of the intermediate input for the product c.

Government procurement

$$Xg_c(t) = \frac{\mu_c(t)}{Pq_c(t)} \left(Td(t) + \sum_d T_d(t) + \sum_d Tm_d(t) + \sum_{zl} Tl_{zl}(t) - Sg(t) \right) \tag{3.15}$$

where $Xg_c(t)$ is the quantity of product c purchased by the government; $\mu_c(t)$ is the proportion of expenditures on product c in the total government expenditure; $Td(t)$ is the direct tax; $T_d(t)$ is the indirect tax from the production of product d; $Tm_d(t)$ is the tariff on the exported product d; $Tl_{zl}(t)$ is the indirect tax of the zlth land use conversion; $Sg(t)$ is government savings.

Investment demand

$$Xv_c(t) = \frac{\lambda_c(t)}{Pq_c(t)} \left(S(t) + Sg(t) + \varepsilon(t)\,Sf(t) \right) \tag{3.16}$$

Demand of household consumption

$$Xp_c(t) = \frac{\alpha_c(t)}{Pq_c(t)}\left(\sum_f r_f(t)\,FF_f(t) + \sum_l rl_l(t)\,FFl_l(t) - S(t) - Td(t)\right) \tag{3.17}$$

where $Xp_c(t)$ is the quantity of product c demanded by household consumption; $\alpha_c(t)$ is the proportion of expenses of product c in the total household expenditure; $r_f(t)$ is the price of the factor f; $FFl_l(t)$ is the total amount of the factor f; $rl_l(t)$ is the price of the lth land; $FFl_l(t)$ is the amount of the lth land; $S(t)$ represents household savings.

$$Xpl_{zl}(t) = \frac{\alpha l_{zl}(t)}{rll_{zl}(t)}\left(\sum_f r_f(t)\,FF_f(t) + \sum_l rl_l(t)\,FFl_l(t) - S(t) - Td(t)\right) \tag{3.18}$$

where $Xpl_{zl}(t)$ is the quantity of the zlth newly-increased land demanded when the family purchases it; $\alpha l_{zl}(t)$ is the proportion of expenditures on the zlth newly increased land in total household expenditures; $rll_{zl}(t)$ is the price of the zlth newly increased land.

Factor demand

$$F_f(t) = \sum_c Fc_{f,c}(t) + \sum_{zl} Fll_{f,zl}(t) \tag{3.19}$$

where $F_f(t)$ is the total demand for the factor f in the tth year; $Fc_{f,c}(t)$ is the demand for the factor f in the production process of product c; $Fll_{f,zl}(t)$ is the demand for the factor f in the zlth land use conversion.

$$\begin{cases} Fc_{f,c}(t) = Y_c(t)\left(\beta_{f,c}(t)\,Py_c(t)/r_f(t)\right) \\ Fll_{f,zl}(t) = Yl_{zl}(t)\left(\beta l_{f,zl}(t)\,Pyl_{zl}(t)/r_f(t)\right) \end{cases} \tag{3.20}$$

Land demand

$$LF_l(t) = \sum_{zl} Fl_{l,zl}(t) + \sum_c L_{l,c}(t) \tag{3.21}$$

where $LF_l(t)$ is the total demand for land in the tth year.

3.1.2.5 Price Module

Price of land supply

$$rll_{zl}(t) = ayl_{zl}(t)\,Pyl_{zl}(t) + \sum_c axl_{c,zl}(t)\,Pq_c(t) + \sum_l \frac{Fl_{l,zl}(t)}{Dl_{zl}(t)} rl_l(t) \tag{3.22}$$

where $Pyl_{zl}(t)$ is the price of the intermediate product of the zlth land use conversion.

Price equation of product supply

$$Ps_c(t) = ay_c(t)\,Py_c(t) + \sum_d ax_{d,c}(t)\,Pq_d(t) + \sum_l al_{l,c}(t)\,rl_l(t) \tag{3.23}$$

where $Py_c(t)$ is the price of the intermediate product in the production process of product c.

Export price

$$Pe_c(t) = \varepsilon(t)\,Pwe_c(t) \tag{3.24}$$

where $Pe_c(t)$ is the domestic price of product c, which is produced at home for export (signified in national currency); $\varepsilon(t)$ is the exchange rate; $Pwe_c(t)$ is the foreign price of product c, which is produced at home for export (signified in foreign currency).

Import price

$$Pm_c(t) = \varepsilon(t)\,Pwm_c(t) \tag{3.25}$$

where $Pm_c(t)$ is the domestic price of import c (signified in national currency); $Pwm_c(t)$ is the foreign price of import c (signified in foreign currency).

3.1.2.6 Tax Module

Indirect tax

$$\begin{cases} T_c(t) & = \tau_c(t)\,Ps_c(t)\,Z_c(t) \\ Tl_{zl}(t) & = \tau l_{zl}(t)\,rll_{zl}(t)\,Dl_{zl}(t) \end{cases} \tag{3.26}$$

where $\tau l_{zl}(t)$ is the indirect tax rate of the zlth land use conversion.

Direct tax

$$Td(t) = \tau d(t)\left(\sum_f r_f(t)\,FF_f(t) + \sum_l rl_l(t)\,FFl_l(t)\right) \tag{3.27}$$

where $\tau d(t)$ is the direct tax rate.

Tariff

$$Tm_c(t) = \tau m_c(t)\,Pm_c(t)\,M_c(t) \tag{3.28}$$

where $\tau m_c(t)$ is the tariff on the product c.

3.1.2.7 Savings-investment Module

Household savings

$$S\left(t\right)=ss\left(t\right)\left(\sum_{f}r_{f}\left(t\right)FF_{f}\left(t\right)+\sum_{c}\sum_{l}rl_{l}\left(t\right)LK_{l,c}\left(t\right)\right.$$
$$\left.+\sum_{zl}\sum_{k}rl_{k}\left(t\right)Fl_{k,zl}\left(t\right)\right) \tag{3.29}$$

where $ss(t)$ is the household savings rate.

Government savings

$$Sg\left(t\right)=ssg\left(t\right)\left(\sum_{c}T_{c}\left(t\right)+\sum_{zl}Tl_{zl}\left(t\right)+\sum_{c}Tm_{c}\left(t\right)+Td\left(t\right)\right) \tag{3.30}$$

where $ssg(t)$ is the government savings rate.

3.1.2.8 Foreign Trade Module

Quantity of imports

$$M_{c}\left(t\right)=\left(\frac{\gamma_{c}\left(t\right)^{\eta_{c}(t)}\,\delta m_{c}\left(t\right)Pq_{c}\left(t\right)}{\left(1+\tau m_{c}\left(t\right)\right)Pd_{c}\left(t\right)}\right)^{1/(1-\eta_{c}(t))}Q_{c}\left(t\right) \tag{3.31}$$

Quantity of exports

$$EK_{c}\left(t\right)=\left(\frac{\theta_{c}\left(t\right)^{\Phi_{c}(t)}\,\xi e_{c}\left(t\right)\left(1+\tau_{c}\left(t\right)\right)Ps_{c}\left(t\right)}{Pe_{c}\left(t\right)}\right)^{1/(1-\Phi_{c}(t))}Z_{c}\left(t\right) \tag{3.32}$$

where $EK_c(t)$ is the quantity of the exported product c.

3.1.2.9 Equilibrium Closure Module

Product market equilibrium

$$Q_{c}\left(t\right)=Xp_{c}\left(t\right)+Xg_{c}\left(t\right)+Xv_{c}\left(t\right)+Xc_{c}\left(t\right) \tag{3.33}$$

$$Pq_{c}\left(t\right)=Pd_{c}\left(t\right) \tag{3.34}$$

$$Pq_{c}\left(t\right)=\left(1+\tau_{c}\left(t\right)\right)Ps_{c}\left(t\right) \tag{3.35}$$

Factor market equilibrium

$$FF_{f}\left(t\right)=F_{f}\left(t\right) \tag{3.36}$$

$$FFl_{l}\left(t\right)=LF_{l}\left(t\right) \tag{3.37}$$

Foreign trade equilibrium

$$\sum_{c} Pwe_c\left(t\right) EK_c\left(t\right) + Sf\left(t\right) = \sum_{c} Pwm_c\left(t\right) M_c\left(t\right) \tag{3.38}$$

where $Sf(t)$ is the total amount of foreign savings.

3.1.2.10 Objective Function

$$\max UU\left(t\right) = \prod_{c} Xp_c\left(t\right)^{\alpha_c(t)} \tag{3.39}$$

As can be seen from the main descriptive equations of the various modules, the CGELUC model involves various socioeconomic levels related to land system structure and not only has openness and convergence at the macroscopic level but also has a solid microscopic theoretical foundation that can better simulate structural changes in regional land use.

3.2 The CGELUC Model Database

The CGELUC model can simulate regional land use structure and its changes because it can simulate and predict changes in total demand of different sectors for developed areas, water area, grassland, forest and unused land based on the thematic quantitative analysis module. It then exports the changes in area of different land use types under different scenarios and inputs these area changes into the area framework of various regional land use types to conduct equilibrium analysis of the area of different land use types.

3.2.1 Database of Thematic Quantitative Analysis

Simulation of developed areas, forest other than economic forest, grassland except pasture, water area and unused land in the thematic quantitative analysis module includes natural environmental conditions, climate change, human population, economic output, industrial structure and other factors (Table 3.1).

In the spatial quantitative model of the thematic quantitative analysis module, Moran's I statistic is used to check for spatial autocorrelation (Deng et al., 2006). Moran's I is defined as follows:

$$Moran'I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(Y_i - \bar{Y}\right)\left(Y_j - \bar{Y}\right)}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{3.40}$$

Table 3.1 Variables to explore the driving mechanisms of land system change in a case study of the North China Plain

Variable	Specific explanation
Geophysical condition	
Landform	0: Hill 1: Plain 2: Terrace 3: Plateau
Soil pH	The higher the value, the lower the soil acidity.
Soil depth	Top soil depth
Average elevation	Average elevation of each 1 km grid
Slope	Slope extracted based on digital elevation model
Climatic variables	
Temperature	Annual average temperature
$\geqslant$ 0℃ accumulated temperature	Accumulated temperature of days with an average daily temperature above 0℃
$\geqslant$ 10℃ accumulated temperature	Accumulated temperature of days with an average daily temperature above 10℃
Sunshine percentage	Percent of sunshine
Total amount, structure and migration of population	
Population density	Disaggregated population density based on the population distribution model
Proportion of non-agricultural population	Proportion of non-agricultural population in the total population in one certain administrative region
Proportion of migrate population	Proportion of the migrate population in the total population in one certain administrative region
Urbanization level	Proportion of non-agricultural population in the total population in one certain administrative district
Agricultural research investment	Proportion of investment in agricultural research
Economic output, industrial structure	
GDP	Total amount of GDP per unit of land area
Share of the secondary industry GDP in the total GDP	Share of the secondary industry GDP in the total GDP in one certroid administrative region
Share of the tertiary industry GDP in the total GDP	Share of the tertiary industry GDP in the total GDP in one certain administrative region
Trade environment	
Tariff rate	Rate of duty to tax the taxpayers set by the tariff rules
Proximity variables	
Distance to the provincial capital	Distance between the center of one administrative region and the provincial capital
Distance to the nearest highway	Distance between the center of one administrative region and the nearest highway
Distance to the nearest provincial highways	Distance between the center of one administrative region and the nearest provincial highway
Policies, shifts of institution	
Subsidies for returning cultivated land	Amount of subsidies for returning cultivated land per hectare
Percentage of cultivated land with slope above 15°	Percentage of cultivated land with slope above 15°

where
$$\begin{cases} S^2 = \dfrac{1}{n}\sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)^2 \\ \bar{Y} = \dfrac{1}{n}\sum_{i=1}^{n} Y_i \end{cases} \tag{3.41}$$

where Y_i is the change in developed areas, ecological forest, ecological commonwealth grassland, water area and unused land; n is the total grid number; and w_{ij} is the spatial weight, assigned as follows:

$$w_{ij} = \begin{cases} 1 & \text{When the distance between } i \text{ and } j \text{ is within certain scope} \\ 0 & \text{When the distance between } i \text{ and } j \text{ exceeds certain scope} \end{cases} \tag{3.42}$$

Positive values of Moran's I indicate the existence of positive spatial autocorrelation among changes in developed areas, ecological forest, ecological commonwealth grassland, water area and unused land and the other factors i.e., natural environmental conditions, climate change, total population and structural change, economic aggregate and structural change. Negative values of Moran's I indicate that there is negative spatial autocorrelation between the aforementioned factors. A zero value indicates random spatial patterns of the factors (Deng et al., 2008).

Spatial autocorrelation is checked by constructing Z statistics (Deng et al., 2010b):

$$Z = \frac{Moran'I - E\left(Moran'I\right)}{\sqrt{VAR\left(Moran'I\right)}} \tag{3.43}$$

where
$$\begin{cases} E\left(Moran'I\right) = -\dfrac{1}{n-1} \\ VAR\left(Moran'I\right) = \dfrac{n^2 w_1 + n w_2 + 3 w_0^2}{w_0^2\left(n^2-1\right)} - E_0^2\left(Moran'I\right) \end{cases} \tag{3.44}$$

where
$$\begin{cases} w_0 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} \\ w_1 = \dfrac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\left(w_{ij} + w_{ji}\right)^2 \\ w_2 = \sum_{i=1}^{n}\left(\sum_{j=1}^{n} w_{ij} + \sum_{j=1}^{n} w_{ji}\right)^2 \end{cases} \tag{3.45}$$

3.2.2 The SAM

The Social Accounting Matrix (SAM) dataset serves as a basis for running the CGELUC model, the construction of which facilitates parameter estimation of the model. The structural change in regional land use is analyzed by expanding the traditional SAM dataset and adding factors and commodities of several land use types balanced among sectors and regions in the CGELUC model. The SAM dataset complements and expands the input-output (IO) tables because it indicates interdependence of production activities, income distribution factors and income distribution of different sectors. It also determines expenditure patterns of different sectors (Table 3.2).

The economic meaning of each land factor in the SAM table is briefly explained below. Macroscopic SAM in the CGELUC model generally describes the economic cycle of production, distribution and consumption in the economic system starting from commodities.

Commodity account #1 in Table 3.2 is mainly used to record various commodities, including the destination of various imported commodities and services. Income of the commodity account mainly comes from the supply of commodities and services to the six economic entities: intermediate inputs for other commodity accounts ($t_{1,1}$), input consumption for the land use conversion process ($t_{1,2}$), consumer goods sold to residents and the government ($t_{1,6}$ and $t_{1,7}$), investment goods for the investment account ($t_{1,8}$) and exported consumer goods ($t_{1,12}$). Expenditures of this type of account are primarily used to purchase other types of commodities as intermediate inputs ($t_{1,1}$), to pay for charges of various production factors (labor, capital and land) ($t_{3,1}$, $t_{4,1}$, $t_{5,1}$) and to pay indirect taxes ($t_{11,1}$) and tariffs ($t_{12,1}$).

Conversion account #2 is mainly used to record the relationship between income and expenditures in different land use conversion processes. Income of this type of account mainly comes from commodities and intermediate inputs in the land use conversion process ($t_{2,1}$ and $t_{2,2}$) in addition to the investment demand of consumption of residents, government and capital for land use conversion ($t_{2,6}$, $t_{2,7}$ and $t_{2,8}$). Expenditures of this type of account mainly include expenses for intermediate inputs of commodities ($t_{1,2}$) and various production factors (labor, capital and land) ($t_{3,2}$, $t_{4,2}$ and $t_{5,2}$). In addition, indirect taxes ($t_{9,2}$) generating from the process of land use conversion are also included in the expenditures.

Labor account #3, capital account #4 and land account #5 are also referred to as factor accounts. The three types of accounts are mainly used to record the origin of income and destination of expenditures of the various initial factors in the production process. Labor, capital and land conversion acquire factor income ($t_{3,1}$, $t_{4,1}$, $t_{5,1}$ and $t_{3,2}$, $t_{4,2}$, $t_{5,2}$) by supplying their own resource endowment to commodity and conversion accounts. Subsequently, this income will be distributed to residents in the form of labor income ($t_{6,3}$, $t_{6,4}$ and $t_{6,5}$) and form the main source of residents' income. Part of the factor income goes into direct tax accounts in the form of direct taxes ($t_{10,3}$, $t_{10,4}$ and $t_{10,5}$).

Income for residents' account #6 includes the distribution of profits of enterprises ($t_{6,4}$), residents' proceeds from land transfer ($t_{6,5}$) and various government transfer payments (such as subsidies) ($t_{6,7}$), besides residents' labor remuneration ($t_{6,3}$).

Table 3.2 Macro SAM table with land factors

		Commodities	Conversion	Labor	Capital	Land	Resident	Government
		#1	#2	#3	#4	#5	#6	#7
Commodities	#1	$t_{1,1}$	$t_{1,2}$				$t_{1,6}$	$t_{1,7}$
Conversion	#2	$t_{2,1}$	$t_{2,2}$				$t_{2,6}$	$t_{2,7}$
Labor	#3	$t_{3,1}$	$t_{3,2}$					
Capital	#4	$t_{4,1}$	$t_{4,2}$					
Land	#5	$t_{5,1}$	$t_{5,2}$					
Resident	#6			$t_{6,3}$	$t_{6,4}$	$t_{6,5}$		$t_{6,7}$
Government	#7							
Capital	#8						$t_{8,6}$	$t_{8,7}$
Indirect tax	#9	$t_{9,1}$	$t_{9,2}$					
Direct tax	#10			$t_{10,3}$	$t_{10,4}$	$t_{10,5}$		
Tariff	#11	$t_{11,1}$						
Rest of the world	#12	$t_{12,1}$						
Total		Subtotal by column #1	Subtotal by column #2	Subtotal by column #3	Subtotal by column #4	Subtotal by column #5	Subtotal by column #6	Subtotal by column #7

Continued

		Capital	Indirect tax	Direct tax	Tariff	Abroad	Total
		#8	#9	#10	#11	#12	
Commodities	#1	$t_{1,8}$				$t_{1,12}$	Subtotal by column 1
Conversion	#2	$t_{2,8}$					Subtotal by column 2
Labor	#3						Subtotal by column 3
Capital	#4						Subtotal by column 4
Land	#5						Subtotal by column 5
Resident	#6						Subtotal by column 6
Government	#7		$t_{7,9}$	$t_{7,10}$	$t_{7,11}$		Subtotal by column 7
Capital	#8					$t_{8,12}$	Subtotal by column 8
Indirect tax	#9						Subtotal by column 9
Direct tax	#10						Subtotal by column 10
Tariff	#11						Subtotal by column 11
Rest of the world	#12						Subtotal by column 12
Total		Subtotal by column #8	Subtotal by column #9	Subtotal by column #10	Subtotal by column #11	Subtotal by column #12	

Resident expenditures mainly include residents' product consumption ($t_{1,6}$), consumption of land use conversion ($t_{2,6}$) and savings investments ($t_{8,6}$).

As the regulator of macroeconomic and relevant policies, the government plays an important role in the process of economic operation and land use conversion. Therefore, it is necessary to introduce the government account into the SAM dataset of the CGELUC model. The revenue of government account #7 mainly comes from various taxes, including indirect taxes ($t_{7,9}$), direct taxes ($t_{7,10}$) and tariffs ($t_{7,11}$). Government expenditure mainly includes government consumption of commodities ($t_{1,7}$), the consumption of land use conversion ($t_{2,7}$), transfer payments to residents, social welfare ($t_{6,7}$) and government savings investments ($t_{8,7}$).

Capital account #8 obtains capital from household savings ($t_{8,6}$), government savings ($t_{8,7}$) and foreign capital inflows ($t_{8,12}$). This capital is converted into investments and then finally provides the investment demand for commodities ($t_{1,8}$) and land use conversion ($t_{2,8}$). Investment and consumption are two key indicators of China's economic development, or the dynamic CGELUC model.

Indirect tax #9, direct tax #10 and tariff account #11 are further separated from the government account. These accounts are independent in order to account for and classify the influence of various government taxes on land use conversion in the CGELUC model. Indirect taxes are mainly charged for the process of commodity production ($t_{9,1}$) and land use conversion ($t_{9,2}$). A direct tax is charged for various production factors (labor, capital and land) ($t_{10,3}$, $t_{10,4}$ and $t_{10,5}$). A tariff is charged on imported commodities ($t_{11,1}$). Income of the three types of tax accounts eventually enters the government account as an integral part of government income ($t_{7,9}$, $t_{7,10}$ and $t_{7,11}$).

Foreign account #12 is mainly used to account for the inflow and outflow of capital in regions outside the study area. This account receives income from the payment of imported commodities in the study area ($t_{12,1}$) and pays for exported commodities from the study area ($t_{1,12}$) and investment consumption of the regional capital account ($t_{8,12}$).

In the SAM table above, the subtotal by row i equals the subtotal by column i; the total investment equals total output. The method used to construct the SAM table is described in detail in the next section.

3.2.3 Preparation of the SAM Parameters

The prices of products and factors are generally set to the same unit since the transaction values involved in the SAM dataset of the CGELUC model are expressed as values. Most of the parameters in the model can be calculated by incorporating equations of the CGELUC model, and the few parameters that cannot be calculated in this way are determined with the quantitative analysis module.

3.2.3.1 Proportion Parameters of the Product Production Module

The consumption coefficients of products $ax_{d,c}$ and $al_{l,c}$ can be directly obtained from the ratios of the intermediate input of commodities and land factor input and the total department output in the SAM $al_{l,c} = LK_{l,c}/Z_c$. The parameter $al_{l,c} = t_{4,1}/\mathrm{COL1}$ is calculated with data in the SAM table mentioned above.

The share of factor f in the production process of the intermediate product c is $\beta_{f,c}(t)$ can be determined from the ratio of the proportion of the quantity of factor f input into the quantity of all factors in the production process of product c in the SAM matrix.

The production scale coefficient of the intermediate product c, or $b_c(t)$, can be calculated with the following formula:

$$b_c(t) = Y_c(t) \Big/ \prod_f Fc_{f,c}(t)^{\beta_{f,c}(t)} \tag{3.46}$$

In the integrated products of domestic sales, the share parameters of imported products $\delta m_c(t)$ and locally produced products $\delta d_c(t)$ can be determined by the ratio of the quantity of imported and locally produced products and the total quantity of domestic sales. The elasticity of substitution $\eta_c(t)$ between the locally produced product c and imported product c cannot be directly obtained through the SAM. These need to be estimated with econometric methods; the setting of these parameters is further described as follows. After obtaining $\delta m_c(t)$, $\delta d_c(t)$ and $\eta_c(t)$, the scale parameter of the Armington function, $\gamma_c(t)$, can be determined with the following formula:

$$\gamma_c(t) = Q_c(t) \Big/ \left(\delta m_c(t)\, M_c(t)^{\eta_c(t)} + \delta d_c(t)\, DK_c(t)^{\eta_c(t)}\right)^{1/\eta_c(t)} \tag{3.47}$$

Relevant parameters of the total quantity of domestic products mainly include the share parameter $\xi e_c(t)$ of the export c, share parameters $\xi d_c(t)$ of product c produced and sold at home, the elasticity of conversion $\Phi_c(t)$ between the domestic product c and exported product c and the scale parameter $\theta_c(t)$ of the transfer function. These parameters are calculated based on processes and approaches similar to those of the integrated products sold at home.

3.2.3.2 Proportion Parameters of the Land Use Conversion Module

In the CGELUC model, land use conversion participates in economic activities as an independent sector similar to other commodity productions. Relevant parameters mainly include the consumption coefficient $axl_{c,zl}(t)$ of the intermediate product c in the land use conversion zl, consumption coefficient $ayl_{zl}(t)$ of other types of land, share of the factor f $\beta l_{f,zl}(t)$ in the production process of intermediate products in land use conversion zl and scale parameter $bl_{zl}(t)$ of the zlth newly-increased land. The calculation is similar to that of $ax_{d,c}(t)$, $al_{l,c}(t)$, $\beta_{f,c}(t)$ and $b_c(t)$.

3.2.3.3 Proportion Parameters of the Demand Module

The proportion parameters of the demand module mainly involve the consumption demand for different products, investment demand, land demand and demand for other factors of economic entities (government and residents). Government consumption should strictly conform to the implemented financial budget in the model. $\mu_c(t)$ is the proportion of the expense of the product c account in total government expenditures, and $\alpha_c(t)$ is the proportion of the expense of consumer good c in total household expenditures.

3.2.3.4 Parameters of the Product Price Module

The price of the product is directly related to the type of production function selected in the production module. In the top-level nest of the CGELUC model, the Leontief linear production function is adopted. The amount of intermediate inputs in the final products will directly affect the price of the final product.

3.3 Methods of SAM Compilation

In general, SAM is the final result of a national economic accounting system, and therefore, the structure and data of SAM are closely related with this accounting system. The SAM that supports CGELUC incorporates three land types (arable land, economic forest and grassland), which clarify the relationship with sectors in the national economy accounting system. National economic accounting is macro-accounting with the country as the main body. Its statistical range covers all of society, the survey method is diverse, the data sources are multiple and the various data are difficult to coordinate. Therefore, the kinds of information collected from different perspectives are complicated and distorted if they are not arranged and coordinated following certain theoretical systems and scientific methods. SAM can be used to appropriately process fragmented and unsystematic data to provide a better overview of the national economy. SAMs not only provide diverse indexes of the national economic accounting system, but also describe the interdependent and mutually-constraining relationship between subsystems in the national economy to provide a scientific basis for macroeconomic system management.

Generally, there are three steps to compile the SAM. First, a highly centralized macroscopic SAM account is established to provide a consistent macroeconomic framework to subdivide SAM in the next step. Second, sector accounts are subdivided based on the issues to be analyzed. In the process of subdividing the macroscopic SAM, data for the unit item in the macroscopic

SAM become the control numbers of the vectors or sub-matrices following the subdivision process. Third, if the disaggregated SAM account does not balance, certain assumptions or processing technologies are adopted to balance it, including the RAS and cross-entropy (CE) methods. The data used to compile the SAM are mainly from the national or regional IO tables, government summary table of annual financial accounts, national income and expenditure statistics, annual tax data, statistical yearbooks, import and export data and surveys of urban and rural residents.

Two methods are widely used to compile SAM. One is a top-down method; the other is a bottom-up method.

Top-down

The top-down method advocates compiling the SAM based on the known total amount and decomposition of the SAM. The data come from national or regional IO tables and national economy and accounting information. The macroscopic SAM provides a description of all macroeconomic activities. However, it is necessary to subdivide this information to obtain the disaggregated SAM to obtain more reliable data to analyze policies (Cramb et al., 2009; Sohl et al., 2010). Supporters of this method, such as Hayden and Round (1982), believe that when the classification level of the country is given, it is unlikely to define the detailed data used to compile the SAM. Clearly, the starting point for compiling the SAM must be the SAM of national economic accounting of a country. In addition, more detailed feedback depends on decomposition of institutional accounts and production departments in the SAM. The 1988 SAM of the United States and the 1987 SAM of China compiled by the State Council Development Research Center were both complied using the top-down method.

Bottom-up

The bottom-up method makes full use of existing information and classifies and summarizes the information to compile the SAM. In contrast with the top-down method, this approach advocates the starting point to be the various detailed data from different sources. It emphasizes data accuracy. However, as detailed data are difficult to obtain, this method is used far less frequently than the top-down method (Brown et al., 2008). Keuning and de Ruijter (1988) support the use of the bottom-up method; they regard it as controversial that the SAM compilation should be based on disaggregated data or aggregate accounting data. However, because the SAM of the national economic accounting data must be available in a timely manner at the end of the year, the information provided is always less than the information SAM should include. Therefore, we are prone to support the use of the top-down method. In this case, the SAM can be used to revise the SAM of national economic accounting rather than have the total quantity deciding the subdivided quantity. Clearly, inconsistencies obtained from initial estimates would feed back to statistical agencies of the country. Therefore, interactions of the construction of the SAM, improvements in basic data and the compilation of the SAM (every 5 years) are iterative processes.

It is necessary to note that the national economic accounts of some countries are unreliable. In such cases, information gained through elaborately designed surveys (such as living standards surveys or multiple-objective surveys) not only provides useful data, but also improves the reliability of the SAM of the national economy. In addition, an elaborately designed, multiple-objective survey also makes an amendment of the national economic account possible. Jabara and Lundberg (1992) used the bottom-up method when compiling the SAM of Gambia, and they believed that inconsistencies existed in the data of the national economic accounting. The SAM based on these data would result in an imbalance between the column and row totals.

As previously mentioned, the bottom-up method is an important method in summarizing relevant collected information, while the top-down method can be seen as a deductive method since it starts with the controlled total amount and divides each total amount to obtain the SAM. An excellent SAM should be based on adequate and accurate data, but since detailed and accurate data are difficult to obtain, the bottom-up method is used more frequently. To some extent, the SAM is a result of multiple iterations between prior continuity and later accuracy.

Supporters of the two methods both start with data. In other words, the key to compiling the SAM lies in the availability and usability of data. It is generally believed that the choice of method should be based on the issues analyzed for the countries and regions that have good databases. Presently in China, the top-down method is more feasible due to restrictions in statistical capacity (Huang et al., 2002).

3.3.1 Compilation of the Macroscopic SAM

Operation of the actual national economic accounting system is an extremely complicated process, the complexity of which is represented as the diversity of economic activities, sectors and products. It is extremely complicated to show all economic activities with the SAM. Generally, a macroscopic SAM should first be compiled, and then the disaggregated SAM is compiled according to research needs. A simple example of structure and compilation methods of a macroscopic SAM is shown below.

First, to form a general macroscopic SAM, all economic activities are defined as activities, all products of economic activities are defined as commodities, all capital and labor inputs are defined as factor inputs, all institution sectors, such as corporations and residents, are defined as sectors and all kinds of product uses are defined as final usage, including activity, product, factor, sector and final usage accounts. Doing so can produce a 5×5 macroscopic SAM, which is the simplest SAM, yet still reflects the process from production to distribution of the final products, and consequently the economy of a country. The specific form of the macroscopic SAM is shown in Table 3.3.

This SAM table includes five types of information. (i) Activity account. Columns indicate inputs of intermediate products and factors in economic activities, i.e., total inputs. Rows indicate the total income of industrial activities from revenues of product sales, i.e., total product outputs. (ii) Product account. Columns indicate that the aggregate supply is from economic activities, and rows indicate that the aggregate demand is from intermediate need and the final usage of the products. (iii) Factor account. Columns indicate factor income distributed to departments, i.e., factor distribution. (iv) Institution account. Columns indicate products the institutions consume, i.e., final use, and rows indicate that the income of the institutions is from factor revenue. (v) Final usage account. Columns indicate final consumed commodities, i.e., final product supply or use. Rows indicate that the final use comes from final demand or consumption of the institutions.

A series of important macroeconomic balances are gained using the macroscopic SAM mentioned above. These gains include balances of the regional total input, total demand, factor income, sector income and final usage.

- Total input = total output = intermediate input+ added value
- Total demand = total supply = intermediate consumption + final product
- Factor income = factor distribution = added value
- Sector income = income usage = added value
- Final usage = final demand = added value

The entire macroeconomy operation process can be described by reflecting macroeconomic account data with the SAM, which makes it superior to the traditional ‘T’ type of account. One method for compiling a macroscopic SAM is to use a descriptive statement, i.e., by obtaining the data that the macroscopic SAM needs using a circular account system of the national economic account. Another method involves directly compiling the SAM through a simplified IO table and some relevant macroeconomic data. The specific case depends on availability of the national economic account data of each country. Generally, the former method can be used if the national economic account system is complete; if it is incomplete or is mainly shown in table form, the latter method can be used.

The SAM of different dimensions may be compiled according to specific conditions. Generally, the fundamental structure of the macroscopic SAM with complete systems for the CGE model is 8×8, i.e., activity, product and factor accounts are retained, and then the sector and final usage accounts are subdivided into the five departments (resident, corporation, government, savings and foreign). With an increase in the number of accounts, the content indicated by these accounts is richer than that of the 5×5 SAM. The activity account indicates the input and output of domestic activities. In the product account, rows indicate the total domestic demand including intermediate demand, resident demand, government demand, investment and

Table 3.3 Structure of a simple SAM

		1	2	3	4	5	
		Activity	Product	Factor	Sector	Final Use	Total
1	Activity		Total Output				Total Input
2	Product	Intermediate				Final Product	Total Demand
3	Factor	Added Value					Factor Income
4	Sector			Added Value			Sector Income
5	Final Use				Final Product		Final Demand
	Total	Total Input	Total Product Supply	Factor	Income Use	Final Use	

import. Columns indicate the total supply including total domestic output and import. The factor account mainly indicates factor input and distribution of factor revenue. In the resident account, rows indicate disposable income including factor income and transfer income, and columns indicate resident expenditure, product consumption, tax and family savings. In the corporation account, which indicates business income and expenditures, rows indicate business capital income and transfer income, and columns indicate business profit distribution and tax. In the government account, rows indicate government revenue such as production tax and income tax, and columns indicate government expenditures and transfer payments. In the investment-savings account, rows indicate resident, corporation and government savings and overseas investment, and columns indicate that the investment comes from commodities. In the foreign account, rows indicate domestic payments to foreign countries, i.e., the foreign exchange expenditure manifested by the import, foreign factor expenditures, the surplus corporations pay abroad and government transfer expenditures. Columns indicate foreign payments to the domestic country, i.e., the foreign exchange income presented as the export, overseas factor income, transfer of foreign currency and foreign transfer expenditures to corporations and foreign investments. The specific SAM structure is listed in Table 3.4.

3.3.2 Subdivision of the Macroscopic SAM

The macroscopic SAM is subdivided into subaccounts. The setting of the subaccounts often differs among countries and has no standard form. This is because (i) the statistical bases and availability of data differ among countries; and (ii) the purposes of policy analysis and forms of established economic models vary, which results in different requirements for subdivision levels.

Two different methods are always available to subdivide an account. The first is to subdivide the entire economic class into unit classes. The activity account and the product account are first subdivided according to industrial and product sectors, respectively, which stand for the IO relationship of production, i.e., the production matrix and usage matrix in IO technology. Consequently, some regard the SAM as an extension of an IO table. In fact, the IO table only describes the relationship between product and institutional sectors, while the SAM describes both the relationship between product and institutional sectors and the relationship between institutional sectors. After the activity and product accounts are subdivided, the factors are then subdivided into labor, capital and land. The business account is then subdivided. Finally, the enterprises are subdivided into state-owned enterprises, shareholding enterprises and foreign-owned enterprises according to ownership, or large-scale enterprises, medium-scale enterprises and small-scale enterprises according to size. Other methods of subdivisions exist and

Table 3.4 Basic structure of SAM

			Expenditure				
			1	2	3	4	5
			Activity	Product	Factor	Resident	Corporation
Income	1	Activity		Market output		Resident self-production and self-consumption	
	2	Product	Intermediate input	Transaction costs		Private consumption	
	3	Factor	Added value				
	4	Resident			Resident factor income	Transfer expenditure among residents	Surplus corporations pay to residents
	5	Corporation		Corporation factor income			
	6	Government	Production tax, value added tax	Sales tax, customs, export tax	Factor income of the government, factor tax	Individual income tax, income tax	Corporation income tax, surplus submitted by corporations
	7	Savings-investment account				Resident savings	Corporation savings
	8	Foreign		Import	Foreign factor income		Surplus corporations pay abroad
		Total	Total input	Total supply	Factor expenditure	Resident expenditure	Business expenditure

Continued

			Expenditure			
			6	7	8	Total
			Government	Savings-investment account	Foreign	
Income	1	Activity				Total output
	2	Product	Government consumption	Investment	Export	Total demand
	3	Factor			Factor income from abroad	Factor income
	4	Resident	Transfer of the government to residents		Transfer of abroad to residents	Total resident income
	5	Corporation	Transfer of the government to corporations		Transfer of abroad to corporations	Total corporation income
	6	Government				Total government income
	7	Savings-investment account	Government savings		Overseas savings	Total savings
	8	Foreign	Payment of the government abroad			Foreign exchange expenditure
		Total	Government expenditure	Total investment	Foreign exchange income	

are based on national statistical status and research purpose. In addition, the subdivision of residents is also an important part of the subdivision of the SAM. Residents can be subdivided into rural and urban residents according to living area or income levels and can even be subdivided according to two standards simultaneously. The foreign account is sometimes subdivided into different countries or country groups in studies focusing on the economic communication between one country and the rest of the world. The accumulation account is subdivided according to institutional sectors and introduces a financial account to expand the SAM into a financial SAM. The assets and liabilities account can even be introduced to expand SAM to combine the flow and the stock. This is an expansion account method in the compilation method of the macroscopic SAM, i.e., a subdivision of the account system.

The other method used to expand the SAM is to subdivide the trade types. Regular transfers among institutional sectors can be subdivided according to differences among regular transfers. For example, resident income tax can be separated from regular transfers of residents to the government. This method directly extracts different transactions separately from the general national economic account. When there are a large number of data, it may be difficult to balance the SAM in the compiling process.

In the compilation of SAM, a disaggregated SAM is obtained by combining the two methods, subdividing the industrial activity and kinds of products and incorporating the macroscopic economic data with the subdivided data of relevant institutions.

The disaggregated SAM, which includes the relationships between product activities and transactions among sectors at the sector level, is ideal to describe mid-level economic flows and can provide large amounts of valuable data for policy analysis and model building.

3.3.3 Balancing the SAM

According to the principles of social accounting, expenditures should equal income, which is shown when the row sum equals the column sum in the SAM. But in the process of compiling the SAM, row sums are usually not equal to column sums due to differences in data sources and the following statistical errors. (i) Inequalities often occur between the row and column accounts in the SAM with the same data source, which defies the principle that the row sum and the corresponding column sum should be equal. (ii) Abnormal data do exist in the table, e.g., negative numbers are input in the intermediate sector in the previous section. (iii) When data items are updated, it is necessary to update the original SAM. It is possible to only add one error account in the SAM to keep the error or to regulate the data in the accounts to balance the SAM.

Generally, three steps are needed to compile the SAM to ensure equality between the row and corresponding column subtotals. (i) The macroscopic SAM is first compiled followed by the more specific SAM. Data in the macroscopic SAM are taken as control numbers for each sub-matrix to ensure that the sum of the data in the sub-matrixes equals the control number. (ii) Inconsistent data are analyzed, a judgment is made according to auxiliary information and data are adjusted. The SAM gathers many different accounts together, the data of which should come from different sources, and a payment of one account must be expenditure for another. The process of analyzing and judging differences in the data also serves as a check for the acquired statistical data. (iii) Data of the SAM are adjusted using mathematical methods such as RAS, CE and least squares to balance the SAM. The theory and steps of RAS and CE are introduced in the following sections (Duan, 2004).

3.3.3.1 The RAS Method

RAS, which is also called the biproportional method, was put forward by Stone (1961), an English economist. RAS was originally used to amend the direct consumption coefficient in the IO table but has gradually extended to balance other matrices. The essence of adjusting the SAM with RAS is to use two main diagonal matrices, namely the alternative multiplier matrix and the manufacturing multiplier matrix. The alternative multiplier matrix is used to left multiply the SAM to reach the required row goal, and the manufacturing multiplier matrix is used to right multiply the SAM to reach the required column goal. The process is repeated until the row and the column in the SAM meet accuracy requirements. The formula for RAS is as follows:

$$\begin{cases} R_i^{(K)} &= u_i^* / \sum\limits_{j=1} t_{ij}^{(k-1)} x_j^{(1)} \\ S_i^{(k)} &= v_j^* / \sum\limits_{i=1} R_i^{(k)} t_{ij}^{(k-1)} x_j^1 \\ a_{ij}^{(k)} &= R_i^{(k)} t_{ij}^{(k-1)} S_j^1 \end{cases} \quad (i = 1, 2, \cdots, n; j = 1, 2, \cdots, n) \tag{3.48}$$

where $R_i^{(k)}$ represents the alternative multiplier matrix left multiplied in the kth step; $S_i^{(k)}$ represents the manufacturing multiplier matrix right multiplied in the kth step; u_i^* and v_j^* represent the sum of the known row vector and the sum of the known column vector in the SAM, respectively; $a_{ij}^{(k)}$ represents the data items in the kth step in the SAM table; $x_j^{(1)}$ stands for the row sum or the column sum of the final SAM.

Adjusting the SAM with RAS balances the row and the column mechanically and forcibly, which may change most data in the original matrix. Therefore, some accurate data in the original SAM may also change, and some reliable information might be lost. To retain the accurate data in the original SAM, some treatment is conducted on the SAM when RAS is used. The accurate data in the original SAM are extracted from the matrix before adjustment, and the corresponding blanks in the matrix are set to zero. RAS is then applied to adjust the matrix. After the adjustment, the extracted data are returned to the adjusted SAM. Row and column sums in the treated SAM remain both accurate and balanced.

RAS can be used to adjust both the full SAM table and the sub-matrix in the SAM. An advantage of RAS is that it does not require complicated software tools. Microsoft Office Excel is capable of easily and simply converting RAS into a planning problem to find the solution. However, RAS is a purely mathematical leveling method; its logic is short of real economic meaning. Therefore, there are many disadvantages of using RAS to adjust the SAM. First, the assumption regarding the consistency of the alternative multiplier and the right multiplied manufacturing multiplier among sectors is dubious and inconsistent with facts. Second, RAS cannot adjust a matrix with negative numbers. Third, the error of the SAM adjusted with RAS is generally very large. To surmount these disadvantages, Byron (1978) put forward an improved RAS method, and Liu (1996) came up with the RAS-weighted amendment method called the RTALS method. These methods are good at balancing the SAM.

3.3.3.2 The Cross Entropy Method

The CE method was originally put forward and applied in statistics and economics by Theil (1967), who was inspired by the theory of information entropy proposed by Shannon (1948). Shannon defined information entropy as $-\ln\frac{p_i}{q_i} = -[\ln p_i - \ln q_i]$, in which p_i and q_i represent the prior probability and the later probability of event E_i, respectively. Therefore, the expectations of the information for event E_i are:

$$-I(p:q) = -\sum_i p_i \ln\frac{p_i}{q_i} \tag{3.49}$$

where $I(p{:}q)$ is the mutual entropy distance between the two probabilities defined by Kullback and Leibler (1951). Theil (1967) subsequently applied this concept to balance the IO table.

CE is mainly used to update the original SAM after gaining the updated sector summary data. Its core idea is to embed the new information into the SAM and to minimize the difference between the updated SAM and the original SAM. The difference is measured by the CE distance suggested by Kullback and Leibler (1951).

Suppose the original SAM is T^0, and all data in the matrix is t^0_{ij}; the updated SAM is T^1, and each data item of the corresponding matrix is t^1_{ij}. Therefore, the CE method can be represented as a nonlinear optimization problem solver; its arithmetic expression is as follows:

$$\min H = \sum_i\sum_j a^1_{ij}\ln\frac{a^1_{ij}}{a^0_{ij}} = \sum_i\sum_j a^1_{ij}\ln a^1_{ij} - \sum_i\sum_j a^1_{ij}\ln a^0_{ij} \tag{3.50}$$

$$\sum_j a^1_{ij}T^1_j = T^1_i, \quad \sum_j a^1_{ij} = 1 \tag{3.51}$$

where a_{ij}^0 and a_{ij}^1 represent the coefficient matrix before and after the adjustment, respectively; i.e., $a_{ij}^0 = \dfrac{t_{ij}^0}{\sum\limits_i t_{ij}^0}$, $a_{ij}^1 = \dfrac{t_{ij}^1}{\sum\limits_i t_{ij}^1}$, T_j^1 and T_i^1 represent the sum of rows and the sum of columns in the updated SAM table, respectively. The objective of the optimization problem mentioned above is to minimize the distance. The constraint conditions indicate that row sums and column sums in the updated SAM table are still equal and are also equal to the updated row sums (or column sums). The EXCEL VBA program of the RAS program code is illustrated in Appendix 1.

3.4 Summary

The CGELUC model selects the framework of CGE to analyze the influence of socioeconomic factors in an equilibrium economic system such as the industrial structure, trade environment, economic policies and institutional arrangements on the structure of regional land use. This model can be used to simulate principles of regional land use structural changes due to constraints and influences at the policy level. The model can also conduct relevant research pertaining to land use such as simulations, predictions, assessments and analyses. The CEGLUC model uses the price signal to organically link the factor market, commodity market and land use subject and forms an equilibrium analysis system covering multiple markets and sectors.

Economic activities are the main driving factors behind structural changes in land use and are also constrained by the structure of regional land use. The CGELUC model analyzes factors that influence the types of regional land use based on macroscopic quantitative analysis, revealing the relationships between economic variables and changes in the area of cultivated, economic forest and pasture lands. Then constructing mechanism-based models to analyze the dynamic laws for the succession of land use structure at the regional scale.

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