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Land Use Change in China: A Scenario Analysis based on Input-Output Modeling

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Contents

Abstract

Land availability is of crucial importance for China's food security and economic development in the next century. Economic growth, urbanization, diet structure changes, and population growth will influence both the demand of and the supply for land. A recursive input-output model enlarged by land is used to develop various scenarios of changes in the economy and society and to evaluate their effects on land-use change in China. Due to inefficiency and structural problems, China's land productivity has ample room to increase significantly above current levels even by further exploiting the potential of the existing technology. Results of some scenarios show that China would not be able to support the increasing demand for land intensive products with its land base without significant improvement in land productivity and/or by increasing imports.

About the Authors

Klaus Hubacek participated in IIASA's Young Scientists Summer Program in 1999, and joined the Land Use Change-project in January 2000 to assess various development scenarios and their effect on land and water, using and developing an extended input-output model for different regions in China.

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Laixiang Sun is a senior researcher, mathematician and economist engaged in developing the economic component of the IIASA-LUC model. He is also affiliated with the United Nations University (UNU), WIDER, in Helsinki, Finland, as a Project Director on property rights regimes, microeconomic incentives, and development, and with Guanghua School of Management of Peking University, in Beijing, China, as a Senior Research Fellow. Prior to these appointments, Dr. Sun was a consultant of UNU/WIDER and teaching assistant of two master degree courses at the Institute of Social Studies, The Hague. In the years between 1985 and 1991, Dr. Sun was a lecturer, and later also Associate Chairman of the Department of Economic Management, and Senior Researcher at the Research Centre for Social Development of Contemporary China, both at Peking University in Beijing, China.

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Land Use Change in China: A Scenario Analysis based on Input-Output Modeling

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I Introduction

Land availability is of crucial importance for China's food security and economic development in the next century. Economic growth, urbanization, changes in diet structure, and population growth will influence both the demand for and the supply of land. Food security in China will also have significant global implications. There are controversial arguments about food demand and supply in China for the next 30 years (e.g. Brown, 1995; Chen et al., 1996; Huang and Rozelle, 1995). But there is agreement that arable land loss and land degradation are undermining China's food production capacity (e.g. Gardner, 1996; Rozelle et al., 1997).

The purpose of this paper is to develop various scenarios representing different economic and social changes and calculate their effects on China's land base within an input-output modeling framework. The output of this paper will provide not only a primary assessment of land-use feasibility with respect to selected scenarios which may represent possible direction of Chinese economy and society in the future, but also an initialization for the dynamic welfare optimum model of IIASA's Land Use Change (IIASA-LUC) Project. The dynamic welfare optimum model of IIASA-LUC intends to establish a more integrated assessment of the spatial and intertemporal interactions among various socioeconomic and biogeophysical factors that drive land-use and land cover change. It aims also to trace the possible adaptive behaviors of economic actors and the resulting consequences under the condition of increasing scarcity of land resources (Sun, 2000).

Various extended input-output models have been widely used for natural resource accounting, material balance, and scenario analysis in the area of ecological and environment assessments. The theoretical extension of input-output modeling is recently named as structural economics (Duchin, 1998). In this paper we employ the structural economics framework to stylize the empirical facts, to establish quantitative analysis of different stages of Chinese economy, and to evaluate the alternative scenarios about future paths of the economy. The core of our approach is a recursive input-output model expended by inclusion of a set of different land categories. The basic logic of input-output modeling is that the various socioeconomic scenarios are first translated into changes in final demand. In order for the final demand of some sector *j* to expand, the output of other sectors must expand as well, corresponding to the input requirements of sector *j*. As all economic activities consume space, in the long-run, in order to achieve significant increases in output, there must be increases or changes in land use and land productivity.

In the present formulation of the extended input-output model we link socioeconomic changes to different types of land via an explicit representation of land requirement coefficients associated with specific economic activities. By this way, land is treated as a parallel of factor inputs such as labor and capital. Both the direct and indirect land-use requirements are caught by the representation of the sectoral interdependence of the input-output model. For our interest, we deal with only the land requirement of each economic sector rather than compensation for the land use. Input-output modeling deals with structural changes via analyzing discrete and explicit changes from one state of the economy to another. These changes in structures are derived from scenarios, which are developed around each question to be explored. For instance, uncertainty about technological developments can be made explicit by introducing new scenarios based on a different set of assumptions. Dealing with structural changes in this way constitutes the most distinguished feature of input-output modeling. This feature makes it powerful in the evaluation of alternative scenarios about future paths for the economy. Through the evaluation of scenarios that reflect current thinking and by pinpointing the insufficient parts in these scenarios as a basis for improving them, scenario analysis based on input-output modeling may be capable of stimulating new insights into the search for promising development patterns for the future.

The paper is organized as follows. In Section 2, we present the basic model and its extensions for including land, as well as the procedure of calculations. In Section 3, we describe the economy and its land base. In Section 4, we develop scenarios for possible major socioeconomic changes, which include economic growth, urbanization, changes in life styles, and population growth. We translate those scenarios into the logic of an input-output framework and estimate the land requirements of the different development options. In the concluding section 5, we discuss the results, critically assess the applied method, and outline the necessities and avenues for further research.

2 The basic model and its assumptions

2.1 Scenario-analysis within a structural economics framework

Structural economics aims to describe and explain many important features of interactions among economic, social, and environmental systems. The emphasis on structure implies an interest in the state of the economic system during a certain interval of time, usually a year. The core of structural economics is the input-output model. The fundamental purpose of the input-output model is to analyze the interdependence of economic sectors. Its extensions include social institutions (e.g., Stone, 1970) and the environment (e.g., Daly, 1968; Ayres and Kneese, 1969).

For a given accounting period (usually, one year), the basic input-output relations are represented by fixed coefficients. It does not mean that coefficients that in principle should be variable were instead treated as constant, but indicates that the physical structure of the economy in the accounting period does not automatically respond to changes in prices. In other words, in the conceptual framework of input-output economics, substitution behavior on the part of consumers or producers is not considered to be a straightforward and instantaneous reaction to prices. When dealing with another state of the economy, corresponding to a different accounting period (another year), usually also a different set of coefficients is established to represent the new structure of the economy. By comparison, in the classical computable general equilibrium (CGE) framework the choice and combination of inputs is endogenous. The coefficients in the input structure change independently in response to changes in relative prices. Hence, in the CGE framework, the technologies represented by the optimal solution are a result of such changes, and there is no easy way to directly assess whether the technology described by the resulting combination of inputs is feasible from a physical point of view and with respect to the current knowledge base (Duchin and Lange, 1995, p. 337).

Unlike the classical CGE models, input-output analysis does not use elasticities of substitution but deals with discrete and explicit changes in structures (Duchin, 1998, pp. 80). These changes in structures are derived from scenarios developed around each question to be explored. Structural changes include the technology used in different sectors, the changes in relative size of different sectors, changes in the composition and magnitude of the different final demand sectors, and the availability and quality of different environmental resources. A central piece of information is technical literature and expert knowledge to provide information on current and potential future production processes, population and other social trends, and the environment. Given a specific research topic, modelers need to first sort out what the important issues are through a qualitative analysis based on literature and expert opinions, then working on identification and quantification of specific variables and parameters.

2.2 The basic input-output model

The mathematical structure of an input-output system consists of a set of *n* linear equations in *n* unknowns:

(1) $x_i = z_{i1} + z_{i2} + \cdots + z_{ij} + \cdots + z_{in} + y_i$, i = 1, 2, …, n.

in which *n* represents the number of economic sectors in an economy, x_i denotes the total output of sector *i* and y_i the total final demand for sector *i*'s product. The flows from industry *i* to industry *j* are represented by z_{ij}. The right-hand side represents the sum of all of sector *i*'s inter-industry sales *(z)* and its sales to final demand *(y)*.

The ratio of input to output, z_{ij} / x_j is denoted a_{ij}:

(2) $a_{ij} = \frac{z_{ij}}{x_j}$

These technical coefficients a_{ij} are assumed to be fixed[1] in a comparative-static analytic framework. That means, each sector uses inputs in fixed proportions, with the assumption that the average expenditure propensities are equal to marginal ones and economies of scale in production are ignored.

Equation (2) can be rewritten, replacing each z_{ij} by $a_{ij}x_j$:

(3a) $x_i = a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{ij}x_j + \cdots + a_{in}x_n + y_i$

or in matrix notion, *A* represents the $n \times n$ matrix of $\{a_{ij}\}$ and *x* and *y* are the corresponding $n \times 1$ vectors:

(3b) $x = Ax + y$

The exogenous variable, final demand *(y)*, appears on the right-hand side and the endogenous variable *(x)* on the left-hand side:

(4) $(I - A)x = y$

Economic effects are estimated by an analysis of the impact of changes in the exogenous factors. Effects in total output *(x)* on the economy are calculated by multiplying the matrix inverse $(I–A)^{-1}$ with vector *(y)* representing the changes in final consumption:

(5) $$x = (I - A)^{-1} y$$

where the term $(I–A)^{-1}$ is usually written as *M*, the matrix of multipliers or Leontief coefficients. Then:

(6) $$M = (I - A)^{-1}$$

The matrix *M* captures the total, direct and indirect, effects of exogenous injections, changes of final demand, on the endogenous accounts of the input-output table. Economic impacts or so-called "backward-linkages" can be divided into direct economic impacts, that is, the gross revenues received by producers for final purchases of goods and services by consumers, government, and exports; and indirect economic impacts, i.e., expenditures on factors of production to input supply sectors triggered by the direct economic impacts.

2.3 The "open" versus the "closed" model

In order for the output of a sector to expand, the total employment in that sector must generally expand as well. The assumption of a well-defined relationship between output and employment - in this case a linear one - allows us to estimate the number of jobs generated by an increase in final demand. Unlike the simple open model, closing the model for employment and consumption makes it possible to take account of the effects induced by an increase in consumer spending stimulated by an increase in wage income. In the closed model, consumer purchases in each sector correspond to constant proportions of wage income, rather than their level being exogenous and constant as in the open model.

The relation between population size and the overall level of economic activities in the developing countries is typically different from that prevailing in advanced industrialized areas. The developed countries can be expected to maintain in the future a close linkage between employment and output (Leontief, 1986, pp. 342). In a developing economy like China, where a substantial part of the labor force does not participate effectively in the production process, such direct relationship between population size and the total level of

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[1] Unless the scenario specifies changes in them.

output can not be assumed to exist. Hence, for our scenario analysis we use the open model without taking induced effects into consideration.

2.4 Extension of the input-output model: land requirements

The land requirement coefficient vector (c_j) is defined as the ratio of total land use in each sector (L_j) over total sectoral output (x_j).

$$(7) \qquad c_j = \frac{L_j}{x_j}$$

The land requirement coefficient vector (c_j) represents land use in hectares per one million Yuan of output of sector j. This is equivalent to the inverse of sectoral land productivity (p_j), which represents the output in Yuan produced on one hectare of land:

$$(8) \qquad p_j = \frac{x_j}{L_j}$$

In the short term, producers might be able to expand their output without significant needs for further land, especially in the case of industrial and service sectors. The link between output and land use is therefore best perceived as a long-run relationship (Xu et al., 1994, p. 162).

In order to link land-use changes in economic sectors (ΔL) to those in land categories (such as cultivated and built-up land, grassland, forestland, etc.), the vector representing changes in output (Δx) is pre-multiplied by a diagonal land requirement coefficient matrix ($\hat{C}$) and a land distribution matrix (R). The future land use (L^F) is the sum of the present land uses (L^P) and the changes in land use triggered by the changes in output (Δx) based on the scenarios:

$$(9) \qquad \Delta L = R\hat{C}\Delta x$$

$$(10) \qquad L^F = L^P + \Delta L$$

The land distribution matrix R gives the mapping relationship between land uses in economic sectors and the natural categories of land, and the attributes in R are the shares of the former in the latter. Section 3.3 will present the technical details for establishing R.

2.5 Steps in the procedure of analysis

Before presenting analyzing details in the following sections, we would like to sketch the procedure of the land-use scenario analysis and indicate the correspondence between the logical steps and the sections.

Step 1: We stylize various scenarios of population growth, urbanization, changes of lifestyles, and economic growth, with explicit consideration of changes in land productivity (Sections 3 and 4).

Step 2: We select several packages of changes which are considered to be the most interesting or most representative among the many possible combinations. This work is done mainly based on literature survey across different research fields as well as international comparison (Sections 3 and 4).

Step 3: We translate the selected scenarios into corresponding future states of final demand by different economic sectors (Section 4).

Step 4: We calculate the technical coefficient matrices, based on the RAS-method, for the selected future years in the scenario schedule (Section 4.1.1).

Step 5: We use the Leontief inverse matrix, $(I-A)^{-1}$, to obtain the scenarios of sectoral total outputs, $x=(I-A)^{-1}y$, which are considered to be driven by final demands in our current setup (Section 4.2).

Step 6: We establish scenarios of land supply and demand and calculate land requirements based on land requirement coefficient vectors and sectoral total outputs for each scenario (Sections 3.2, 3.3, 4.1.5 and 4.2).

Step 7: Finally, we compare the results from different land use scenarios against various land limits and calculate the required land-productivity growth rate to keep the land requirement feasible (Sections 4.2 and 5).

3 Representation of the economy and land use

3.1 China's economy in an input-output framework

In our analysis we use the input-output tables for 1992, which were compiled by the Chinese National Statistical Bureau (SSB). They are industry by industry tables, with the assumption of homogeneous sector output (i.e., no joint products). This means that each commodity is produced by only one industry and each industry produces only one product. Tables are provided at three levels of detail: 6, 33, or 118 sectors. Due to the emphasis on six agricultural sectors and the absence of a one-to-one relationship in the sectoral classification in these tables, we start from the 118-sector model. The table is aggregated to reflect the significance to the national economy of the various sectors (see Table 6, Appendix). Being the major land use sectors, the primary sectors are maintained in full detail, including six sub-sectors: grains, other crops, livestock, forestry, handicraft, and fishing. Other sectors are industry, construction, transport, trade, and services.

We use the classification categories of the National Statistical Bureau of "non-peasants" for urban population and "peasants" for rural populations. Unfortunately, there are gross inconsistencies in the SSB-classification system for urban, rural, and city population, because the system mixes territorial and functional definitions. The definitions have also been changed over time and non-recorded migration from rural to urban areas further distorts the actual residency (Heilig, 1999).

Value added categories, reflecting the value of factor inputs, are capital income, labor compensation, taxes, and profits. Institutions include Government, investment, inventory, and net-exports. The negative numbers in the export column reflect a negative trade balance. The error column is necessary to balance the table and can be considerable in some instances. For example, the error in accounting for industry transactions is higher than the number representing net-export of industrial goods.

3.2 Extension of the input-output model: land requirements

The input-output model was extended to reflect land use. The land use data were derived from the IIASA-LUC database. A number of fairly large and detailed geographical databases on China including biophysical attributes of land and statistical data at the county level have been implemented in the LUC geographical information system. These data sets allow us to estimate the land used in each of the economic sectors.

Although China has a total area of some 960 million hectares (9.6 million km^2), which is the third largest in the world, only about 14.8 percent are cultivated (field crops and horticulture). Lands unsuitable for agriculture, such as mountains, deserts, or dry grasslands, cover a large fraction of the country. The land suitable for cultivation is largely located only in the coastal and central parts of the country (Sun and Li, 1997).

According to a recent assessment of land production potential in China (Fischer, van Velthuizen, and Nachtergaele, 1999) about 197 million hectares have cultivation potential for grain. Of this land, some 35 million hectares are only marginally suitable for low-input grain production. The remaining 162 million hectares, of which 132 million hectares are currently used, are variously suited for cropping. As Heilig concludes "the bottleneck is not land, but the availability of investment capital, agricultural know-how, and infrastructure in remote areas." Under the requirement of land suitable for high input-agriculture, meaning mechanization and intensive fertilizer use, China has only some 118 million hectares that are potentially suitable.

Table 1: Land-use pattern in China in 1990 (in 1000 hectares):

Economic Sectors	**Land Use (in 1000 hectares)**	**Percent of total land**
Grain	107,592	11.25%
Other Crops	33,051	3.46%
Forestry	205,546	21.49%
Livestock	303,912	31.78%
Fish	34,640	3.62%
Handicraft	33	< 0.01%
Industry	1,412	0.15%
Construction	197	0.02%
Transportation	7,136	0.75%
Trade	537	0.06%
Services	537	0.06%
Urban Residents	3,040	0.32%
Rural Residents	12,128	1.27%
Unused (incl. error)	246,573	25.78%
TOTAL	956,334	100.0%

Source: IIASA-LUC database

Notes: Land use for Other Crops includes horticultural use.

In the Chinese land-use database, horticultural land is distinguished from cropping land. Although, it has little meaning in practice to distinguish land uses for grain production from those for non-grain crops because they are typically inter-cropped in a given cropping rotation, for the purpose of our input-output modeling, we make an analytical distinction by employing the share of sown areas for grains in the total sown areas for crops (*Rural Statistical Yearbook of China*, *1993*, p. 87). Following this analytical classification, about 33 million hectares or 3.5% of China's total land area is used for horticulture and other crops. The most important sub-groups include oil seeds, cotton, sugar cane, tobacco, orchards, tea plantations, mulberry fields, and tropical crops (Fischer et al., 1996).

Most forests in China are sub-tropical and temperate forests, which have fewer species and require longer growth periods than tropical forests. Forestland covers about 205 million hectares of land, representing 21.5% of China's land area. Closed forests are about 100 million hectares. Only about 74 million ha are available for the supply of industrial wood at present. In addition, there are 20 million ha of industrial plantations, of which only 0.7 million ha are available today for industrial wood supply (Nilsson, 1999). The remaining area includes forest stand area, scattered forests, shrub wood, and reforestation areas. The estimated forest stock is reported to have steadily increased, from about 7 billion cubic meters (m^3) in the 1950s to about 10 billion m^3 in the late 1980s (Fischer et al., 1996). However, other researcher (e.g. Liu, 1998) claim that timber stocks are drastically decreasing due to increased consumption, withering, fire damage, and insect damage. Liu states that if no action were taken, China would lose all its timber stocks in the near future. Nilsson (1999) shows that the felling of industrial wood at the current rate of 197 million m^3/year exceeds the annual increment of 176 million m^3/year in growth of natural forests and industrial plantations. For 1992, Liu estimates the present forest stock to be about 5.3 billion m^3.

The largest land-use category in China is grassland with some 304 million hectares (327 million according to Fischer et al., 1998) or 31.8% of total land. Some 6.1 million hectares are improved or sown grassland and the rest is natural grassland (Chen and Fischer, 1998, p. 17). Pastureland in China is either steppe, mainly distributed in the arid and semi-arid zones of Northern China, or grass on mountains and sloped land located in the agricultural regions. Some 91% of the steppe land and about 59% of the grass slopes are used for livestock production (Fischer et al., 1996, p. 56). Only some 10 percent of the total grasslands can be considered as high-yield grasslands with an annual dry-matter production of more than 2000 kg/ha. Almost 60 percent of the best pasture productivity class are scattered in the Northeast economic region (Chen and Fischer, 1998, pp. 17).

The total water area for fish farming, including fishponds, paddy land, coastal waters, and wastelands (some of which is waterlogged) amounts to some 34.6 million hectares, which is 3.6% of total land in China. About half of the total fish production is from fish farms; the remainder is from ocean or freshwater fishing. Fishing on paddy land provides about 1 percent of total fish production (*Rural Statistical Yearbook of China*, *1993*, p. 146).

Built-up land is used for residences, transportation, production, handicraft, mining, and services. It amounts to some 25.8 million hectares and accounts for about 2.6 % of the total land. In some areas of the eastern provinces, settlement areas cover already more than 10% of the total land and are further increasing. Rural settlements account for almost two thirds of total settlement and mining areas. The existing data for settlement areas are not consistent (State Land Administration, 1994; Fischer et al., 1996). Moreover, there might be an overlap between settlement areas, service sectors, and transportation in urban areas. In order to distinguish the various land uses in service and industrial sectors, we make assumptions based on production and population shares.

The category of other lands comprises those unsuitable for habitation and useless for biomass production, such as deserts, glaciers and permanent snow, bare land and rocks, sandy and saline land. This category accounts for one quarter of total land in China.

This data, together with the data provided by the input-output tables, allows us to calculate land requirement coefficients and land productivity coefficients. For all sectors other than forestry, livestock, and fisheries, equations 7 and 8 in section 2.4 can be directly used to conduct these calculations.

For calculating the land requirement coefficient in forestry, we have to consider the fact that present day harvest rates may reduce the total forest stock and thus future harvests (see Liu, 1998; Nilsson, 1999). This consideration prevents us from directly using the total output of forest sector as provided by the input-output tables for the calculation. Instead, we choose the estimated sustainable yield of 4.3 t/ha as provided by the Ministry of Agriculture (1998). This sustainable harvest rate is multiplied with an "average price" of 165.11 Yuan/m^3 for lumber (*Price Statistical Yearbook of China*, *1992*, p. 363) yields a land requirement coefficient of 1,408 ha/million Yuan and a land productivity measure of 710 Yuan/ha. Using this sustainable yield rather than the coefficient based on present harvest rates allows at least constant output levels in the future under the assumption of maintaining the present-days forest management technologies.

To calculate the coefficients for the livestock sector in China, it is necessary to be aware that this sector is heavily depended on feed-crops for raising pig and poultry in the farm sector rather than in the pastoral sector. The inputs of feed-crops into the livestock sector take two forms: direct consumption of grains and other crops and purchase of processed feed from the industrial sector. The land-use implications of both feed-crops and processed feed lie in the grain and other-crops sectors, which have been directly taken into account in these two sectors. The output share of the farm-based livestock production was about 65.15 percent in 1992 (*Rural Statistical Yearbook of China, 1993*, pp.60-64). In the future, China's livestock production will certainly further depend on modernized farms rather than the traditional pasture, as clearly indicated in *Agriculture Action Plan for China's Agenda 21* (Ministry of Agriculture, 1999, pp.13-14). Following this agenda we assume that the share of meat production from the farm-fed animals in the livestock sector in 2025 would be not less than 75 percent. In order to show different modes of livestock production, we calculate two sets of land requirement and productivity coefficients: a lower productivity coefficient (thus higher land requirement coefficient) representing present-day state of pure pastoral livestock, which accounts for about 35 percent of the total livestock production; and a higher productivity coefficient representing a hypothetical state in which 100% of livestock production is based on pastoral land (Table 2). Because grassland in China is used mainly for pasture, we will focus only on the pastoral sector to evaluate required changes in grassland productivity.

Concerning fisheries, it is reasonable to assume that only fish farming may claim more land in the future. At present about half of the total aquatic output is from fish farms. We assume that this share remains stable in the future. The Ministry of Agriculture (1998, p. 28) estimates 3 tons output per hectare of water area in fish farms today. Based on this productivity estimation and to apply an average price for fish products of 5,100 Yuan per ton (*Price Statistical Yearbook of China , 1992*), we can get an independent bench-mark land requirement coefficient for the sector of fish farming.[2]

The current land productivity coefficients shown in Table 2 represent average productivity of the total acreage in a given land use category. The use of these coefficients in scenario analysis would give us the land requirement at present-day efficiency. Land use coefficients and productivity measures provided by the State Planning Commission, which are based on rather small samples, are usually too optimistic in comparison to the actual average productivity.

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[2] Based on Table 1 and the national input-output table to calculate the land requirement coefficient for the fish farming sector gives a very low figure of 885 Yuan/ha. It indicates that the land stock for fishery presented in Table 1 might be double the size of the real fish-farming land. Because we are interested mainly in incremental land requirement, the accuracy of land requirement coefficient become much more important than that of corresponding land stock figure.

Table 2: Land requirement and land productivity in China in 1992

Economic Sectors	Land Requirement Coefficients (ha/million Yuan)	Land Productivity (1000 Yuan/ha)
Grain	375.0	2.7
Other Crops	152.0	6.6
Forestry	700.3	1.4
Pastoral Livestock	2,928.0	0.3
Livestock (hypothetical)	1,024.8	1.0
Handicraft	0.6	1,667.0
Fish farming	65.4	15.3
Industry	0.4	2,635.0
Construction	0.4	2,635.0
Transportation	35.9	27.8
Trade	0.8	1,183.0
Services	0.6	1,608.0

Table 2 presents the land-use coefficients and land-productivity coefficients based on the data and assumptions described above. The land requirement coefficients show the number of hectares required for producing one million Yuan of output. The highest land requirement coefficients and lowest land productivity are for forestry and livestock production. The land productivity of the transportation sector looks relatively low at first glance. It is, however, a result of the fact that about 77 percent of transportation land in China consists of unpaved roads in rural areas (Fischer, *et. al.*, 1996: Section 5.7).

3.3 Spatial development

Primary farmland is located mainly in the same geographic areas where population and major economic activities have been concentrated. About one billion people (out of China's population of 1.2 billion) are concentrated in less than one-third of the land area. The high concentration of population is essentially explained by the highly concentrated distribution of arable land (Heilig, 1997). To get a better understanding of the dynamics of farmland, it helps to distinguish cropland from general farmland. The conversion of cropland into fishponds and horticultural lands following the market-driven restructuring requirements of the agricultural sector would actually increase the food security. The conversion of cropland into forest and grassland according to the requirement of conserving soil resources and environment is also desirable from a long-term perspective. Between 1988 and 1995, such cropland conversions amounted to 2.97 million hectares (Fischer *et al.*, 1998: Tables A4.1-4.8).

One of the permanent losses of cultivated land is due to construction activities for the creation of infrastructure, housing, and industrial activities. Between 1988 and 1995, China lost some 0.98 million ha of cultivated land to construction activities, which is about 0.75% of the total cultivated land in China. Growing economic activities and population density in Eastern China, where most of the country's arable land locates, will inevitably lead to further decline of cropland areas. Urban infrastructure expansion will reduce cropland areas; increasing urban (air) pollution and waste discharge will affect soils and irrigation systems; and growing urban freshwater consumption will compete with agriculture for water supply. Urbanization not only causes an expansion of built-up areas for housing, but also has far-reaching effects on indirect land-cover change triggered by additional land needs, which include service infrastructure, dams for hydropower generation, special areas for sewage treatment and waste disposal, and recreation areas. These additional needs will further take away cropland areas around the cities. Cropland areas will not only shrink because of urban sprawl, but also due to the growing land requirements of villages and rural infrastructure.

China's food security can potentially be threatened by losses of cultivated land due to disasters, water and wind erosion as well as chemical and physical deterioration. Agricultural over-exploitation and industrial pollution also exacerbate these degradation problems. However, hard data on pollution are scarce and the pollution is restricted to certain - relatively small - areas (Heilig, 1999; Lynden and Oldeman, 1997). Over-exploitation and degradation might be more severe in the case of forestland and grassland (see also the discussion in Section 4.1).

To make up for the losses or even extend the existing land base, farmland reclamation has been emphasized in China's agricultural policy. However, the potential for reclamation seems quite limited in view of farmland conversion following business cycle in general and rural industrial booming in particular. The losses of fertile farmland mainly occurred in the southeastern part of the country, where irrigation conditions are good and the multi-cropping index is high. Whereas the reclamation mainly took place in the marginal zones located along the boundary between cropping and non-cropping areas (Sun and Li, 1997, p. 22). The average productivity of reclaimed land is only between 30 and 50 percent of that of existing farmland, depending on the available technology (Ministry of Agriculture, 1998). In addition, conversion possibilities of other land categories to farmland are very restricted. For example, only about 0.5 percent of grassland, 4 percent of woodland, and 2 percent of forestland are suitable for conversions to high input cropping agriculture (Fischer and Velthuizen, 1998).

In order to see which land categories might be suited to future development, we created scenarios in the Geographical Information System using the agro-ecological zones data (Fischer et al., 1999). We assumed that existing industrial areas and urban and rural agglomeration would expand by different rates, with higher growth rates for medium sized agglomerations[3]. Following these assumptions and the GIS accounting, we get Table 3, which shows the distribution of land use by activity. This table allows us to disaggregate a single number representing "homogenous" land into several categories of land as it traces the linkage between land-uses in economic sectors and natural categories of land. It would also be possible to further disaggregate the various land categories into those with different qualities of land (e.g. from very productive farmland to moderate to minor productive farmland).

The entries in Table 3 are numbers between *0* and *1*, which quantify the categories of land-used by economic sector. The numbers do not represent current patterns of land-use but rather future land-use development. As the table shows, we assume that various land-use options, such as residential land, industrial land, horticulture, and fish, compete for cultivated land, grassland, and forestland. The category of unused or multiple use land represents a residual value. In the case of fish, for example, fish are farmed on agricultural land without diminishing the usage of agriculture land. Multiple use does not decrease the ability to use land for other production purposes. Sectors utilizing built-up land are assumed to expand also in part on previously unused land.

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[3] In the GIS-model, we expanded existing agglomerations of more than 20 square kilometers by adding an additional ring of 1 kilometer, to the outskirts of each existing built-up area. Agglomerations smaller than 20 squarekilometers are assumed not to grow. By this way, medium-sized agglomerations will grow much faster than the largest ones.

Table 3: Distribution of land use by activity (R-matrix) in 2025

	Cultivated Land	Grassland	Forestland	Water	Unused or Multiple Use Land	Total
Grain	1.00	0	0	0	0	1.00
Other Crops	1.00	0	0	0	0	1.00
Forestry	0	0	1.00	0	0	1.00
Livestock	0	1.00	0	0	0	1.00
Handicraft	0.67	0.11	0.17	0	0.05	1.00
Fish	0.1	0	0	0.89	0.01	1.00
Industry	0.67	0.11	0.17	0	0.05	1.00
Construction	0.67	0.11	0.17	0	0.05	1.00
Transportation	0.67	0.11	0.17	0	0.05	1.00
Commerce	0.67	0.11	0.17	0	0.05	1.00
Services	0.67	0.11	0.17	0	0.05	1.00

4 Major driving forces and their effects on land-use change in China

The scenarios, as described below, are designed to systematically explore possible development paths for the Chinese economy by the year 2025 and to take account of major social changes. Eight scenarios, labeled *A-H*, were developed for the main driving forces in the early next century: technical change, economic growth, population growth, urbanization, and lifestyle changes. Comparison of scenario outcomes helps inform a judgement about whether improvement of technology and more efficient use of land will be able to offset the inevitable increases in final demand caused by these trends. The scenarios are summarized in Table 4.

In the Scenarios, major factors are varied step by step to show individual effects of each of the driving forces. *Scenario A* represents the present-day situation, with current technology and population level, no migration to urban areas, present-day diet pattern, and today's economic structure. *Scenario B* is based on assumptions representing technology available in year 2025. For *Scenario C*, we add final demand changes caused by a population of 1.49 billion people, which represents a medium-variant projection of United Nations Population Division (1998), but keeping migration, diet, and economy on the level of year 1992. In S*cenario D*, we include effects of urbanization and life-style changes. Economic growth is included in S*cenario E*. *Scenario F* is designed to see the effects of a higher population estimate of 1.55 billion people (Shen and Spence, 1996, 1997). *Scenario G* differs from S*cenario F* in that built-up land is restricted to maximal 4 percent of total land whereas in all other scenarios built-up land is linearly connected to rural and urban population and output in certain sectors. *Scenario H* differs from S*cenario G* only by assuming the existence of more efficient technologies in year 2025.

Table 4: Scenarios representing major social and economic driving forces in China.

	A	B	C	D	E	F	G	H
Technology	1992	2025a	2025a	2025a	2025a	2025a	2025a	2025b
Population (in billion)	1.21	1.21	1.49	1.49	1.49	1.55	1.49	1.49
Migration to urban areas	No	No	No	Yes	Yes	Yes	Yes	Yes
Diet change	No	No	No	Yes	Yes	Yes	Yes	Yes
Economic Growth	No	No	No	No	Yes	Yes	Yes	Yes
Built-up Land	Variable	Variable	Variable	Variable	Variable	Variable	Max. 4 %	Max. 4 %

In this section, we first describe the major driving forces and develop the assumptions for a number of scenarios. In a second step, we calculate the land requirements corresponding to each scenario using input-output analysis. We also analyze the extent of the necessary technical advancement that would be needed to meet future requirements with the given land base.

4.1 Description of the scenarios

4.1.1 Technical change

To highlight the crucial role of technological development in the future we describe three different scenarios representing different technologies. In the S*cenario A*, "China 1992, Technology 1992", we use today's technology as represented in the technical coefficients of the A_{1992}-matrix (Table 7, Appendix) and in the land requirement coefficients of Table 2. We will apply these coefficients to the present-day situation and calculate the resulting land requirement. This will be compared with the S*cenario B*, "China 1992, Technology 2025a". In this scenario we apply land saving technologies that might be available in the year 2025 to present-day economy and society. The technology 2025a is also used for the other Scenarios, *C* through *G*, representing different economic and social changes. Finally, we compare these changes with S*cenario H* (technology 2025b), which represents an optimistic view for solving the requirements for food and fibers of the next century using higher growth rates in land productivity than Scenario *B* through *G*.

The Technology Matrix for year 2025 (A_{2025})

China's economic success was accompanied by enormous productivity gains. Yet China's economy is still characterized by substantial inefficiencies and backward technologies and therefore has enormous possibilities for improvements. The World Bank (1997a, p. 20) estimates that annual growth rates of total factor productivity of 5 to 7 percent during 1995 - 2020 will lead to major changes in the sectoral structure of production and employment. For example, agricultural employment is expected to fall from more than half of total employment today to one-quarter within the next 25 years. We used the structural changes as projected by the World Bank (1997a) together with our own assumptions to calculate technical coefficients for the year 2025 using the RAS technique.[4]

The RAS approach is a mathematical procedure,[5] in which a new coefficient matrix is generated by solving an optimization problem subject to row and column margins, represented by the totals of intermediate output (U_{2025}) and intermediate purchases (V_{2025}). The underlying logic is that, given limited information, we would assume the A matrices for the year 1992 (A_{1992}) and for the year 2025 (A_{2025}) to be sufficiently close to each other subject to the constraints which represent the new information set. Concretely speaking, given the additional information about the relative size of the various sectors and the value-added components of the Chinese economy in 2025, we can minimize the difference between A_{1992} and A_{2025} (Budavari, 1982, p. 404):

$$(14) \quad D[A_{1992} : A_{2025}] = \sum_i \sum_j \left\{ a_{ij}(2025) \left[ln\left(\frac{a_{ij}(2025)}{a_{ij}(1992)} \right) - 1 \right] \right\}$$

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[4] An alternative way to estmate the coefficients of the A-matrix for the year 2025 is to estimate each indivual entry based on expert knowledge, technical data base or other scientific information (Duchin and Lange 1995).

[5] The term RAS refers to a mathematical procedure for adjusting, sequentially, rows and columns of a given input-output coefficient matrix, $A(0)$, in order to generate an estimate of a more recent matrix, $A(1)$, when only the new structural information of sectoral output, $X(1)$, intermediate deliveries, $U(1)$, and intermediate purchases, $V(1)$, are assumed known. Once the procedure converges, the final outcoming used to be denoted as $A(1) = RA(0)S$, in which R is a diagonal matrix that is the product of a series of diagonal matrices, and so is S.

This minimization of the RAS objective function would generate the least "surprising" representation of A_{2025} because it fully incorporates both the historical information A_{1992} and the new structural information X_{2025}, U_{2025}, and V_{2025}.

Land requirement coefficients *(c_j)*

To show the effects of technical change on the acreage of land required, we have to calculate a new set of land coefficients. For this, we incorporate both predictions concerning future development of technology and policy intentions as expressed in the Agricultural Action Plan for China's Agenda 21 (Ministry of Agriculture 1999). These effects are not fully incorporated in the A_{2025}-matrix. They are only implicitly and partly reflected in the A-matrix generated via the detour of the RAS method, which focuses on the input-output linkages across economic sectors.

In our scenarios on land requirement coefficients, we focus mainly on primary sectors, because of their significant effects on land use.

In grain production, average yields in China are generally higher than those of all developing countries but still well below the averages in developed countries. Future growth of grain production via significant yield growth could be achieved by spreading the applications of updated hybrid seeds, balanced utilization of chemical fertilizer and pesticides, increasing use of other modern inputs such as plastic film, farming machines, as well as power for agriculture use, investment in agricultural infrastructure such as irrigation and drainage facilities, and agricultural research (Heilig, 1999; Lin, 1995; Lin, et al., 1996; Nickum, 1982; World Bank, 1985, 1997b). In addition, the Ministry of Agriculture plans to classify over 80% of farmland as basic farmland conservation zones by 2010, indicating a firm effort to insure the sustainable development of the food sector.

The average increase in land productivity in the grain production for the period of 1950 - 1977 was 3.1 percent. There is a debate on the magnitude of the future performance of grain production. For example, the World Bank used yield growth rates of 0.5 to 1% for their estimations assuming favorable water availability (World Bank, 1997b). Huang and Kalirajan (1997) came up with similar estimates using a stochastic varying coefficients frontier approach based on household survey data. Lin, Huang, and Rozelle (1996, p. 83) used projections of yield increases in grain production of 1.4 to 1.7% per year, depending on investment in research and irrigation, world price impact, salinity and erosion, and opportunity costs of labor and land. Cao, Ma, and Han (1995) estimated that the average potential yield of all cereal crops could be 92% higher than the current actual yield based on average potential primary productivity. This would translate into a yield growth rate of some 2% until the year 2025. Lin (1995) argues that the grain yield potentials are in general two to three times the current actual yield levels. For our scenarios, we follow the Agricultural Action Plan of China's Ministry of Agriculture with a target of grain yield per unit area increase by 1% per year. This reduces the land requirement coefficient from 375 (at the level of 1992) to 270 ha/million Yuan. We assume similar land-productivity growth for other crops.

In forestry, future development could go in the opposite direction. Although, the estimated forest stock is reported to have steadily increased from about 7 billion m^3 in the 1950s to about 10 billion m^3 in the late 1980s (Fischer et al., 1996, see also Section 3.2), the timber densities in China are very low with 30 m^3/ha to 84 m^3/ha in comparison to World's timber densities of about 100 m^3/ha (Ministry of Forestry, 1990). In consideration of the fact that the efforts to improve forest management concerning fires, usage of pesticides, and higher forest densities are under way and strengthened, we assume a total productivity growth in forest production of 20 percent from 1992 to 2025.

Very similar is the situation for livestock production. The productivity of grasslands in China is much lower than in other parts of the World (Chen and Fischer, 1998), which severely limits the development of China's livestock industry. The Chinese Ministry of Agriculture (1999, p. 45) states that China has a serious problem of grassland degradation with over 50% of the Northern grassland being degraded and the remainder degrading at the rate of 1.9% annually. To maintain and further improve the quality of grassland, the Ministry of Agriculture plans to apply measures such as pest and rodent control, monitoring, conservation zones, and enclosed pastures. The improvement of 360 million mu (25 million hectares) of pasture is planned by the year of 2010. The Ministry of Agriculture (1999) hopes that China can maintain a stable output of animal husbandry in the pastoral areas before 2010 and can start to increase the pastoral land productivity afterward. With reference to this practical consideration, we assume an accumulative land productivity growth of 10 percent for the whole period of 1992-2025 in the pasture sector.[6]

[6] As we have indicated in Section 3.2, the calculation of a land requirement coefficient for livestock excludes lands for growing processed and unprocessed feed-crops, but it still includes lands for keeping pork and poultry, which are not grassland. Although the keeping of pork and poultry in China does not consume noticeable amounts of lands, this inclusion means that we may still overstate the land productivity of the livestock sector by a relatively small margin in all scenarios.

The coefficient for fishery is derived from sample data (see previous section) and already above the average productivity. We use these numbers without further increasing land productivity in this sector.

The assumption of constant land productivity in industrial, service, transportation, and construction sectors implies that economic development follows previous spatial expansion patterns, without taking into account the modernization impact of existing cities and urban areas. Much of the infrastructure is already in place, the improvement and extension of this infrastructure would only require marginal additions of land. Future development might mainly necessitate a restructuring of existing areas and infrastructures. Following this consideration, we develop two different sets of scenarios. In one group of scenarios, *A-F*, we will use the calculated land requirement coefficients based on today's land efficiency for built-up land (see Table 2). In these cases, for urban and rural infrastructure (excluding transport) plus residential areas we assume 100 m^2 and 150 m^2 per person for rural and urban residents, respectively, which is about 10% higher than today's average numbers. For the expansion of transportation land, we assume a yearly growth rate of 0.05%[7]. In the other set of scenarios, *G* and *H*, we assume that total built-over land is expanded by 50% to some 4% of total land by 2025, which is comparable to the share of built-up land in large developed countries.

4.1.2 Population growth

When the People's Republic of China was founded in 1949, it had a population of 540 million; three decades later its population was more than 800 million; and today China's population has exceeded 1.2 billion people. Today's population has created a strong population momentum that is now driving China's population growth despite already low levels of fertility (Heilig, 1999). In its most recent (medium variant) projection, the UN Population Division estimates that China's population will increase to 1.49 billion in 2025 and then slightly decline to 1.48 billion in 2050. We use the UN projection as a basis for the S*cenarios B–E, G and H*. For S*cenario F*, "population: 1.55 billion", we use a somehow higher population projection of Shen and Spence (1996). To see the effects of different sizes of populations on the land base in China we have to compare S*cenarios B* and *C*. This

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[7] Even though the liturature shows a much higher expansion rate for paved roads, in consideration of the fact that about 77 percent of China's transportation land consists of unpaved rural roads, such an expansion rate of total transportation land could be compatable with a much higher expansion rate of paved roads. According to the World Bank (1994, p. 26), in low income countries, paved roads increased by 1.6 percent annually during the last 25 years, in comparision to 0.9 percent in middle-income countries.

represents a jump from today's population to 1.49 billion in 2025. *Scenario F* represents a further increase from 1.49 billion to 1.55 billion people.

The final demand patterns corresponding to these population scenarios are calculated as follows: we multiply average expenditure of the typical urban and rural resident at current level by the total numbers of urban and rural residents in these different scenarios, respectively, while maintaining the relative share of urban and rural residents at present level so that the urbanization impact can be separately analyzed. Other final demand components were linked to household consumption according to their current proportions in the level of total household consumption.

4.1.3 Urbanization and change in diet

It is not only important to represent the quantitative change of China's population but also to consider its regional concentration and the change in consumer's preferences, especially, the increase in meat consumption.

Urbanization

A crucial characteristic of China's demographic situation is the concentration of its large population in the eastern part of the country, especially in the coastal zone. A large part of China's land is virtually uninhabited, such as the Gobi Desert, the steep slopes of the Himalayas, and the vast dry grasslands of the north-central region. Roughly 1 billion people (or more than 90% of the population) live in only a little more than 30% of China's land area. The population density of this area is 354 people per square kilometer. The skewed spatial distribution of the population is a consequence of the country's uneven distribution of climate and physical environment, but is also due to an increasing rate of migration.

Despite the fact that the urban population is constantly increasing, China can still be considered a predominantly rural society. In 1997, only some 30% of the population lived in urban areas. The rather recent increase in urban population is mainly due to the promotion of towns into cities and loosening the strictly controlled internal migration to meet the labor demand of the growing cities and towns. In recent years, there has been a wave of temporary rural-urban labor migration, called the "floating population" (Heilig, 1999). For S*cenario D*, "lifestyles", we assume, based on UN projections (United Nations, 1998), that about 50 percent of the Chinese population would live in urban areas by 2025.

Change in diet

In China's food tradition, cereal products have been of overriding importance. Other food products such as meat, fishery products, vegetables, and fruit played only a residual role in human diet. This pattern has been changing due to recent social and economic developments. Urban residents typically prefer a more diverse diet and eat more processed foods. They are eating more meat and dairy products, which has boosted livestock production. China's population has enormously increased meat consumption and also eats more fruits and vegetables, whereas direct consumption of grain has leveled off or even declined. Despite these developments, China's average food calorie supply per person per day is still below the average level of developed countries (FAOSTAT, 1998). Therefore, an increase in per capita calorie consumption is expected in the future. There is also the possibility that other demographic factors such as the age composition of the population might affect overall food demand.

Changes in consumer demand have been by far the most important reason for agricultural restructuring and thus the transformation of China's cropland into horticultural land and fishponds. Institutional and supply-side factors are also very important. It has become much more profitable for Chinese farmers to grow vegetables and fruit and sell it for market prices rather than to produce rice or wheat, which is still regulated by the state's procurement system. These changes in supply and demand side factors are reflected in changes in land use. From 1988-1995, 1.2 million ha of land for crop production were converted to horticulture, which is equal to 25 percent of the total decrease of cropland, and 0.23 million ha (4%) were converted to fishponds (Fischer *et al.*, 1998).

Estimates of future demand for meat are difficult to make. The vast differences in the estimated results are directly related to the different parameters and research methods adopted in different studies. Furthermore, great inconsistencies of the data on meat consumption and output exist due to a combination of reported data on the supply side and survey data on the demand side (Feng, 1997, p. 211).

In this regard, a comparison of per capita calorie intake across some representative countries may help a lot. We used the statistics of the Food and Agriculture Organization (FAOSTAT 1998) for this comparison. Today's food calorie supply of animal products in China is about 467 kcal per person compared to 503 in South Korea, 600 kcal in Japan, and 1,006 in USA. The average consumption for developed country is 867 kcal. In addition, today's calorie intake of fish in China is behind other Asian countries. Currently, food calorie supply of fish in China is 29 kcal, compared to 92 kcal in South Korea and 194 kcal in Japan.

To calculate changes in lifestyles, S*cenario D*, we assume that the average meat consumption per capita would increase by 25 percent and the currently rather low figure for fish consumption would double by 2025. To meet the remaining calorie intake requirement we use the projections for per capita food grain consumption of Wu and Findlay (1997, p. 286). These together make the S*cenario D* similar to the current diet pattern of Japan and South Korea.

4.1.4 Economic growth

Since 1978, China's economy has expanded at an average rate of nearly 10 per cent - and total exports at 17 percent - per year. China's Five-Year Plan for 1996-2000 targets an annual GDP growth of 8 percent. The Fifteen-Year Perspective Plan identifies two fundamental transitions to sustain future growth: from a traditional planned economy to a socialist market economy and from the extensive growth path, based on increases in inputs, to an intensive growth fashion, driven by improvements in efficiency. Measures to sustain further growth include the restructuring of the 1,000 largest state-owned enterprises, promoting science and technology, developing machinery, electronics, petrochemicals, automobiles, and construction as the pillar industries, and stimulating the growth of basic agricultural products, especially grain, cotton, and oilseed (World Bank, 1997a). Assuming the continuance of the high saving rates supporting high investment rates, of political reforms, and of high factor productivity growth, the World Bank projected growth rates of annually 6.6 percent until 2020. The projection for individual sectors are ranging from 3.8 percent for agricultural sectors, 6.6 percent for industrial sectors, to 7.6 percent for service sectors (World Bank, 1997a, p. 21). The pace of GDP growth will be slowing down over time, from 9-10 percent today to 5 percent in 2020 due to a then stagnating labor force, diminishing marginal returns, and lower gains from structural change in consideration that resources in mature economies are usually more efficiently allocated.

We put a slightly heavier weight on these slow-down factors and we use a slightly lower projection than that of the World Bank for S*cenario E*, "economic growth". We use these growth rates also for *Scenarios F - H.*

4.1.5 Supply of land

Economic and demographic factors, as discussed above, will affect not only the future demand of food, but also food supply via the availability of land. To calculate the available cultivated and built-up land, we assume that in 2025 there will be 162 million hectares of land available (see also the discussion in Section 3). The built-up land in 2025 includes the land presently used for infrastructure and buildings and a part of current cultivated land, which will be converted to built-up land. For grassland and forestland we assume that in 2025 about the same amount of land will be available as today due to proper land conservation measures and forestation. This means that there will be some 304 million hectares of grassland and some 94 million hectares of forestland, the latter of which consists of natural forest areas and industrial plantations. We have not included the 17 million hectares of undisturbed forests into our calculations. For both categories, grassland and forestland, we have to subtract the land which will be used for built-up areas in the future. Future urban or built-up areas are derived from simple scenarios in the GIS as described in Section 3.3.

In summary, the assumptions on land availability presented here give the upper limits for the major agricultural land-uses in the future, because they indicate a rough quantitative balance between reclamation and losses between 1992 and 2025, which looks quite optimistic for a rapidly industrializing country like China. In our analyses, such upper limits can serve as benchmarks for calculating required growth rates of land productivity based on different social and economic scenarios.

4.2 Results of the scenarios

Figure 1 shows how the range of assumptions of social and structural economic changes, as described in section 4.1, affect the total land requirement. We also compare these effects across three major land categories: cultivated and built-up land[8], forestland, and grassland.

In the category representing cultivated and built-up land, the scenarios including economic growth and population growth, (*E, F*) are exceeding the limits of available land. This is also true for the assumption of restricted expansion *(G)* of built-up land. Only the best technology scenario (*H*) with yield growth in both the grain and other crop sectors of 2 percent per year until 2025 requires less land than what is actually available. The biggest

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[8] Conversion for built-up land originates from all three major land categories. However, following the historical trend, the major part is from the category of cultivated land. As socioeconomic infrastructures can happen to a certain degree on all lands, we do not include built-up land as a separate land category.

jump in additional demand for cultivated land is caused by the economic growth Scenario *(E)*. The difference between Scenario *C* and *D* indicates that given the income level, urbanization has significant farmland-saving effect due to that it saves residential and other build-up land, and reduces grain consumption of migrants by a very large margin. As a result, if the income level keeping unchanged, the reduction of direct demand for products grown on cultivated land would not be offset by an increase in indirect demand triggered by the higher consumption of animal products.

The situation is similar in the case of grassland. The scenarios including economic growth and population growth are exceeding the available grassland areas. The biggest jump in demand for additional grassland is caused by the economic growth (*E*) and secondly by lifestyle changes, especially meat consumption (*D*). Only under the additional assumption of a 1.1 percent increase in output per given grassland area (*H*), the additional demand for pastoral livestock production would be met within the limits of available land.

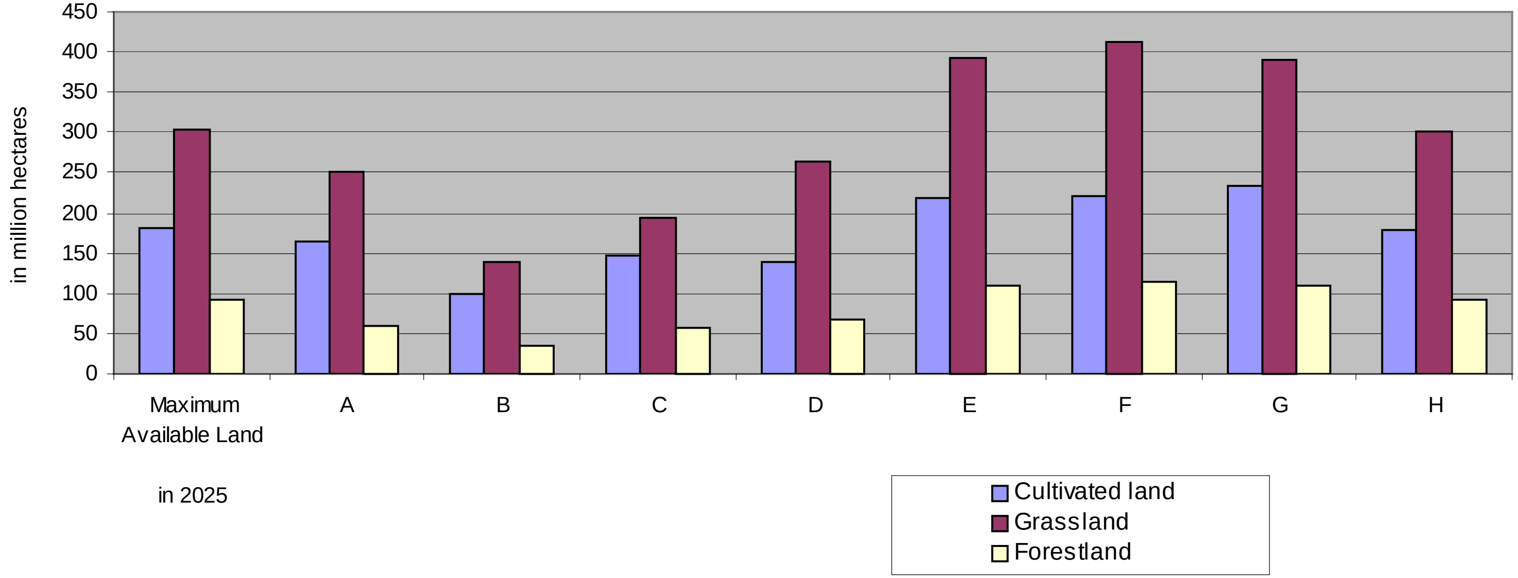
The demand for forestry products exceeding the available forestland appears in *Scenarios* (*E, F, G*). In order to meet the increase in demand for forest products, an annual forestland productivity growth of 1.2 percent ("technology 2025b") is required as well. In the cases of losses of forestland or smaller growth rates of industrial plantations than assumed, there would not be enough forestland to meet the increase in demand for forest products. In all of the scenarios, trade balances of land intensive products are kept proportionally to today's imports and exports.

In the cases of demand exceeding its land limits, additional imports would be necessary. Without additional net imports the growth in land-productivity needs to be higher than the ones usually expected in the literature for the next 30 years, which is represented in *Scenario E*. In order to see how much this extra growth in land productivity will have to be, we calculate the difference of land productivity growth implied in *Scenarios E* and *H*. Table 5 shows the corresponding results. We can see from Table 5 that an extra land productivity growth rate of one percent is required for crop production and of 0.8 percent for pastoral livestock production.

Table 5: Necessary improvements in land productivity

	Extra annual growth in land productivity	Necessary annual growth in land productivity
	(H vs. E)	**(H vs. A)**
Grain	1.00%	2.00%
Other Crops	1.00%	2.00%
Forestry	0.54%	1.22%
Pastoral Livestock	0.80%	1.09%

Figure 1: Land requirements of different scenarios (in million hectares)



	A	B	C	D	E	F	G	H
Technology: 2025a		X	X	X	X	X	X	
Technology: 2025b								X
Population: 1.2 billion	X	X						
Economy 1992	X	X						
Population: 1.488 billion			X	X	X		X	X
Population: 1.55 billion						X		
Economy: 2025					X	X	X	X
Lifestyles: 2025				X	X	X	X	X
Share Urban-Rural of 2025				X	X	X	X	X
Restricted Expansion							X	X

5 Implications of alternative development scenarios for land-use change

In this paper, we select diverse scenarios which are based on different combinations of the widely expected scenarios on population growth, changes of lifestyles, level of migration, and economic growth for the next 30 years, and show how these might affect demand for different types of land in China. The resulting increases in final demands and sectoral outputs would drive the associated land requirements to exceed the available land area. In other words, China would not be able to support the increased demand for land-intensive products with its land base without significant improvement in land productivity and/or increasing imports.

All three land categories face severe shortages for many of the scenarios. The most severe shortage will be for cropland, which is a consequence of population and economic growth, as well as the enormous anticipated increase in demand for livestock products and thus for feed-crops. The final demand for cropland would exceed the supply derived from the then existing land base. Under the condition of a continuing self-sufficiency in grain and food, to keep the farmland requirement feasible, a high annual land-productivity growth rate of about 2 percent is required, which is higher than those usually expected for the next 30 years. On the other hand, however, it is widely believed that due to current inefficiencies and structural problems, China's land productivity may have ample room to increase significantly above current levels even by further exploiting the best currently available technology. The extent of the necessary productivity improvement is indicated by the "success" of the optimistic technology scenarios.

Further productivity growth is also required to compensate for loss and degradation of available land. With reforestation and improved soil management, the chances of substantially eliminating erosion have increased. The loss of cultivated land, forestland, and grassland, especially around urban areas, poses a severe problem in many provinces. Our assumption about future allocation of land for built-up areas is based on calculations using a Geographical Information System in which the present agglomerations are expanded to 4% of total land area. At this point, we have no information about priorities of expansion of the cities and existing infrastructure for a thirty-year time horizon. Currently, much converted cropland to non-agricultural uses is used inefficiently by land-extensive development projects and so-called "horizontal" expansion of urban agglomerates. Strict measures must be implemented and enforced to minimize construction-related losses of cultivated land. China needs concepts for infrastructure development that minimize land requirements, especially in the rapidly developing coastal provinces. After emergence of land-use master plans, zoning regulations or other political and legal measures for future land use, this new information can be incorporated into further scenarios.

The influence of climate change on the land productivity in the various primary sectors can be explicitly incorporated into the model. Because of the enormous uncertainties about these effects, we did not include any scenarios on climate change. There is no agreement in the literature of how climate change will affect the various regions of China. For example, recent findings of the LUC-project at IIASA found that land productivity in the North, the North-East, and the North-West will be positively affected from climate change, whereas the South of China might face negative effects on land productivity (Tang *et al*., 1999).

The results of our study have to be viewed with caution for another reason. Even if future land requirements could be satisfied, we do not say anything about the sustainability of the utilization of land by the various economic sectors because both the reclamation potential and yield growth potential are largely dependent on irrigation and water control. At this point of the input-output analysis we do not make any estimation of water availability and its effects on future land-use changes. In addition, some productivity growth scenarios presented in this paper imply a higher use of pesticides and equipment. In this regard, future work should also pay attention to the energy needs and emission of greenhouse gases and other pollutants of the various development and technical options of the primary sectors.

Scenario analysis based on an expanded input-output model is particularly suited to this research agenda. The mathematics of the model allows accounting for indirect effects or round-by-round effects of final demand, which are created by the inter-industrial linkages of production. We have, for example, seen from Table 6 that in 1992 about 63% of grain were used to fulfill the demand for grain as intermediate uses in other sectors, especially in the livestock sector and food-processing sector (the industrial sector in our set-up). Even though some industrial or service sectors need only small amounts of grain per unit of their output, the effect on grain demand in the future can be substantial considering the very high growth rates of these sectors.

The land requirement coefficients applied in the model represent average land productivity for the total of each land-use category in China. Even though it is popular to use average coefficients in the literature, we feel that lots of information on a regional level is being lost, which might even affect the validity of the results on a national level. For future work, we will try to remedy this situation in developing scenarios based on eight large economic regions in China. These regions show quite different biophysical and socioeconomic features. Working in a regionalized framework allows the calculation of more accurate land requirement coefficients, and the formulation of regional growth patterns within China.

Despite the shortcomings mentioned above, the present model is an important trial to link the social and economic dynamics of China with their effects on China's land base, in a relatively comprehensive and well-interpretable way.

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7 Appendix

Appendix A: List of variables

A	Endogenous coefficient matrix,
c_j	land requirement coefficients per industry,
I	Identity matrix,
L_j	Total land use per industry $_j$,
L^F	Future land use
L^P	Present land use
M	Multiplier matrix or Leontief coefficients
p_j	Sectoral land productivity
R	Regional distribution matrix,
x	Total output,
y	Final demand,
z_{ij}	Flow of input from sector *i* to *j*,
Δ	Change of a parameter
ΔL	Change in land use,

Appendix B:

Table 6: Input-Output Table for China's Economy in 1992 (in million Yuan)

	Grain	Other Crops	Fore-stry	Live-stock	Handi-craft	Fish	Industry	Cons-truction	Trans-port	Trade	Services	Rural	Urban	Govern-ment	Invest-ment	Inven-tory	Ex-ports	Error	SUM
Grain	27,171	3,610	33	43,814	3,353	1,710	97,785	19	9	2,701	1,193	95,265	3,486	0	0	7,644	21	-1,054	**286,760**
Other Crops	1,645	8,562	18	5,391	617	108	82,393	112	2	3,616	1,039	58,722	47,695	352	0	3,124	4,957	-1,089	**217,264**
Fore-stry	147	338	4,330	344	551	24	17,927	519	3	323	270	2,730	1,946	0	13,891	558	-1,249	-391	**42,261**
Live-stock	0	0	0	11,301	0	0	63,520	0	0	5,554	702	95,402	59,631	0	7,836	1,618	1,937	-1,449	**246,052**
Other	481	604	91	1,555	7,278	37	20,579	1,192	6	603	365	11,738	9,584	0	0	866	-58	-143	**54,778**
Fish	0	0	0	0	0	3,423	10,269	0	1	7,857	653	16,816	18,952	12	0	1,419	1,957	-2	**61,356**
Indus-try	49,397	39,299	2,811	35,214	5,684	9,888	1,869,922	293,287	66,887	152,720	233,337	259,486	287,262	24,439	271,093	95,128	12,127	13,208	**3,721,189**
Cons-truction	37	39	7	24	5	13	1,679	3,570	330	5,703	11,828	**37,273**	**37,273**	0	422,426	0	0	96	**520,303**
Trans-port	2,516	2,233	316	3,449	474	703	60,073	14,613	2,235	61,333	23,230	4,115	6,201	249	3,707	-318	12,045	1,544	**198,717**
Com-merce	6,256	4,620	390	5,740	1,149	1,438	277,870	44,697	9,630	25,469	39,450	55,546	63,785	60,259	36,180	21,863	-22,830	3,379	**634,891**
Ser-vices	6,473	5,793	1,204	7,634	1,519	2,348	156,689	8,337	7,247	78,067	91,346	57,379	90,258	327,796	2,021	0	16,170	2,545	**862,826**
Capital	5,632	3,877	1,186	5,575	1,697	2,399	184,355	12,242	27,991	21,142	87,642								
Labor	167,833	126,950	27,512	109,605	28,198	32,947	277,002	99,087	29,831	91,949	214,329								
Taxes	6,009	8,087	1,517	4,283	1,120	2,243	242,316	14,214	9,603	8,851	29,141								
Profits	13,162	13,253	2,846	12,124	3,132	4,075	358,811	28,413	44,941	169,004	128,301								
SUM	**286,760**	**217,264**	**42,261**	**246,052**	**54,778**	**61,356**	**3,721,189**	**520,303**	**198,717**	**634,891**	**862,826**								

Table 7: Intermediate coefficients (A-matrix) of China's economy in 1992

	Grain	Other Crops	Forestry	Livestock	Handicraft	Fish	Industry	Construction	Trans-portation	Trade	Services
Grain	0.09475	0.01661	0.00079	0.17807	0.06121	0.02786	0.02628	0.00004	0.00004	0.00425	0.00138
Other Crops	0.00574	0.03941	0.00042	0.02191	0.01126	0.00176	0.02214	0.00022	0.00001	0.00569	0.00120
Forestry	0.00051	0.00156	0.10245	0.00140	0.01006	0.00039	0.00482	0.00100	0.00002	0.00051	0.00031
Lifestock	0.00000	0.00000	0.00000	0.04593	0.00000	0.00000	0.01707	0.00000	0.00000	0.00875	0.00081
Other	0.00168	0.00278	0.00214	0.00632	0.13287	0.00060	0.00553	0.00229	0.00003	0.00095	0.00042
Fish	0.00000	0.00000	0.00000	0.00000	0.00000	0.05579	0.00276	0.00000	0.00001	0.01238	0.00076
Industry	0.17226	0.18088	0.06652	0.14311	0.10377	0.16115	0.50251	0.56369	0.33660	0.24055	0.27043
Construction	0.00013	0.00018	0.00016	0.00010	0.00010	0.00021	0.00045	0.00686	0.00166	0.00898	0.01371
Transportation	0.00877	0.01028	0.00749	0.01402	0.00866	0.01146	0.01614	0.02809	0.01125	0.09660	0.02692
Commerce	0.02182	0.02126	0.00923	0.02333	0.02097	0.02344	0.07467	0.08591	0.04846	0.04012	0.04572
Services	0.02257	0.02666	0.02849	0.03102	0.02774	0.03827	0.04211	0.01602	0.03647	0.12296	0.10587

Table 8: Intermediate coefficients (A-matrix) of China's economy in 2025

	Grain	Other Crops	Forestry	Livestock	Handicraft	Fish	Industry	Construction	Trans-portation	Commerce	Services
Grain	0.14587	0.02814	0.00191	0.19684	0.09790	0.04577	0.00679	0.00003	0.00004	0.00216	0.00069
Other Crops	0.00909	0.06823	0.00102	0.02484	0.01811	0.00291	0.00971	0.00020	0.00001	0.00344	0.00076
Forestry	0.00079	0.00262	0.24927	0.00154	0.01608	0.00064	0.00112	0.00083	0.00001	0.00025	0.00015
Lifestock	0.00000	0.00000	0.00000	0.05224	0.00000	0.00000	0.00803	0.00000	0.00000	0.00541	0.00053
Other	0.00267	0.00484	0.00525	0.00720	0.21394	0.00099	0.00270	0.00211	0.00003	0.00060	0.00028
Fish	0.00000	0.00000	0.00000	0.00000	0.00000	0.09112	0.00044	0.00000	0.00001	0.00539	0.00031
Industry	0.28310	0.32186	0.16355	0.16732	0.16805	0.26842	0.42263	0.55966	0.34836	0.18004	0.22904
Construction	0.00020	0.00031	0.00040	0.00011	0.00015	0.00035	0.00015	0.00599	0.00156	0.00496	0.00769
Transportation	0.01514	0.01898	0.01854	0.01709	0.01415	0.01929	0.03294	0.03156	0.01275	0.09671	0.03385
Commerce	0.03765	0.03926	0.02286	0.02844	0.03428	0.03946	0.15143	0.09646	0.05490	0.04008	0.05734
Services	0.03878	0.04906	0.07049	0.03767	0.04530	0.06435	0.07868	0.01779	0.04097	0.11959	0.12800

Table 9: Matrix of multipliers or Leontief coefficients for 1992:

	Grain	Other Crops	Forestry	Livestock	Handicraft	Fisheries	Industry	Construction	Trans-portation	Commerce	Services
Grain	1.122	0.036	0.009	0.225	0.091	0.049	0.079	0.049	0.030	0.035	0.029
Other Crops	0.019	1.053	0.006	0.038	0.023	0.014	0.056	0.035	0.021	0.026	0.021
Forestry	0.003	0.005	1.115	0.005	0.015	0.003	0.013	0.009	0.005	0.005	0.005
Livestock	0.009	0.009	0.004	1.058	0.007	0.009	0.043	0.027	0.016	0.025	0.016
Other	0.006	0.007	0.004	0.012	1.156	0.004	0.016	0.012	0.006	0.007	0.006
Fisheries	0.002	0.002	0.001	0.003	0.002	1.061	0.009	0.007	0.004	0.017	0.005
Industry	0.488	0.491	0.212	0.508	0.371	0.470	2.298	1.411	0.853	0.792	0.785
Construction	0.002	0.002	0.001	0.002	0.002	0.002	0.005	1.011	0.005	0.014	0.018
Transportation	0.027	0.028	0.017	0.036	0.025	0.030	0.063	0.077	1.041	0.130	0.058
Commerce	0.069	0.068	0.031	0.077	0.062	0.070	0.194	0.213	0.126	1.123	0.124
Services	0.063	0.067	0.051	0.080	0.067	0.081	0.144	0.121	0.103	0.201	1.178
SUM	**1.811**	**1.769**	**1.452**	**2.043**	**1.822**	**1.793**	**2.920**	**2.974**	**2.210**	**2.374**	**2.245**

Table 10: Matrix of multipliers or Leontief coefficients for 2025:

	Grain	**Other crops**	**Forestry**	**Livestock**	**Handicraft**	**Fisheries**	**Industry**	**Construction**	**Trans-portation**	**Commerce**	**Services**
Grain	1.181	0.046	0.011	0.253	0.155	0.068	0.024	0.015	0.009	0.011	0.009
Other Crops	0.021	1.083	0.008	0.038	0.034	0.013	0.024	0.015	0.009	0.011	0.008
Forestry	0.003	0.005	1.333	0.004	0.029	0.002	0.004	0.003	0.001	0.001	0.001
Livestock	0.008	0.008	0.006	1.061	0.006	0.007	0.019	0.012	0.008	0.011	0.007
Handicraft	0.007	0.010	0.011	0.013	1.276	0.005	0.008	0.008	0.003	0.003	0.003
Fisheries	0.001	0.002	0.001	0.001	0.001	1.102	0.003	0.003	0.002	0.007	0.002
Industry	0.755	0.805	0.547	0.600	0.634	0.730	2.042	1.242	0.779	0.557	0.617
Construction	0.003	0.003	0.003	0.002	0.003	0.003	0.004	1.009	0.004	0.008	0.011
Transportation	0.067	0.073	0.063	0.063	0.065	0.071	0.112	0.112	1.064	0.140	0.081
Commerce	0.180	0.188	0.134	0.150	0.168	0.179	0.346	0.317	0.194	1.153	0.178
Services	0.151	0.166	0.180	0.138	0.161	0.180	0.241	0.184	0.149	0.218	1.232
SUM	**2.374**	**2.390**	**2.298**	**2.322**	**2.531**	**2.359**	**2.827**	**2.920**	**2.222**	**2.121**	**2.148**