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LONG-TERM PERSPECTIVE ON POPULATION AND FOOD SUPPLY AND DEMAND IN ASIA BASED ON EMPIRICAL EQUATIONS AND BaU SCENARIOS

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Abstract

Asia is experiencing rapid economic development due to industrialization, accompanied by massive increases in resource and energy consumption as well as increases in the emission of pollutants. Concerns have arisen about the large and accelerating environmental load imposed by this development. In order to demonstrate the necessity of an environment-oriented policy shift to incorporate environmental considerations into development policy, it would be useful to present forecasts of the possible future environmental situation based on business-as-usual scenarios. This paper posits that the relationship between economic and environmental factors follows some universally applicable curves irrespective of national and local differences. Based on this proposition, it uses per-capita income as a descriptive variable for deriving empirical equations ("learning curves") that relate per-capita income to various environmental indicators in countries around the world. Next, it proposes a particular scenario for future economic growth in various Asian nations and apply the above-mentioned equations for the perspective on population, and food demand and supply.

KEYWORDS: *environmental forecasting, environmental problems in Asia, food supply forecast, development and environment*

1. Introduction

The Asian region including Japan, Korea, China, ASEAN countries and India is undergoing rapid economic development through industrialization. This region is expected to experience even more remarkable development in the future, making it the centerpiece of worldwide growth in the 21st Century. At the same time, the region encompasses nearly half of the world's total population, and economic growth is leading to dramatic increases in resource and energy consumption as well as pollutant emissions (ESCAP, 1995; Japan Environment Agency, 1995). As a result, concern is growing over the environmental load imposed by economic growth. The ability of the Asian region to achieve sustainable development in the coming century will have a major impact on the future global environment. A major policy shift is required to incorporate environmental considerations into development policy.

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In order to elucidate the necessity of an environment-oriented policy shift, it is necessary first of all to forecast future environmental conditions under a business as usual (BaU) scenario where no change in current national policies, in the pace of economic development, and in trends in environmental change will occur. Then it is needed to examine what policies can and ought to be implemented in order to change the forecasted result. The perspective under BaU scenario will allow us to identify problems which regions and nations confront, enabling us to engage in a scientifically-founded discussion over policy options for sustainable development.

One method for forecasting long-term environmental change in developing countries is to extrapolate the past economic development of developed countries. Developing countries can learn from both the successes and failures of their predecessors, and can pursue a more effective catch-up strategy. This paper will demonstrate that development paths everywhere in the past world adhere fairly closely to universally applicable curves. Based on this observation, it will adopt per-capita income as a descriptive variable for deriving empirical equations ("learning curves") that relate per-capita income to various environmental indicators in countries around the world. Then, the future situation on population and food supply and demand in the Asian countries will be examined.

2. Environmental Forecasting Methods

2.1 The Significance of Top-Down Approaches

A number of models have already been developed for global environmental forecasting (Klein *et al.*, 1995; Morita, 1996). These models may be broadly categorized into bottom-up and top-down models: the former assimilate detailed data on region-specific and sector-specific factors, while the latter are based on general equations that relate a comparatively small number of them. Initially typical top-down models were developed such as the model used in "The Limits to Growth" by the Club of Rome (Meadows *et al.*, 1972), largely due to shortage of data. These top-down models based on a limited number of factors and a limited amount of data often lead to over-generalized conclusions. Because of these limitations, efforts have been made into formulating bottom-up models that rely on solid data collection (AIM Project Team, 1995).

It should be noted, however, structural changes or paradigm shifts often cannot be explained by the summing up of data no matter how thorough and voluminous they may be. Environmental problems arise from a complex interplay between natural systems and social systems. Bottom-up models face limitations in attempting to explain these sorts of dynamic changes of social and environmental systems. This barrier can be observed from the relationship between macroeconomics and microeconomics, or between thermodynamics and classic dynamics of many body system (Haken, 1980). Moreover, there are limitations on data collection.

Good correlation is often observed between economic factors and a variety of environmental factors. This leads us to a macroscopic perspective that resource usage and the environment will change according to a definite pattern relative to economic growth. Some relationships between economic and environmental factors are universally observed regardless the level of development or regions, while others are found within particular national and regional circumstances. Factors related to physiological phenomena such as average life expectancy and total food consumption represent instances of the former. The latter are represented by factors such as consumption of animal foods and the number of motor vehicles, both of which are largely influenced by local social conditions. It is supposed that when the differences in environmental and social conditions are properly accounted for and examined, empirical principles should emerge for the relationship that can be applied universally.

2.2 Deriving Learning Curves

A broad range of different factors such as industrial production, resource consumption, and living standards change as people become more economically wealthy. These changes have an adverse impact upon the environment, while at the same time economic growth also increases demands for a better environment and it makes it possible to put more resources to work for solving environmental problems.

Fig. 1 presents a conceptual diagram of environmental load generation due to economic growth. Economic development changes various factors of a country. How it changes them can be deduced by the past experiences. The consequences of these changes could then be predicted as well. Circumstances peculiar to each nation or region may affect these relationships, or a feedback from the environmental consequences to economic development may occur. Nevertheless, factors of the economic development such as per-capita income tend to determine the general condition of the environmental quality, and GDP per capita (referred to hereafter as "GDP/c") has been widely used in a number of studies as an indicator of a nation's level of economic development (World Bank, 1992).

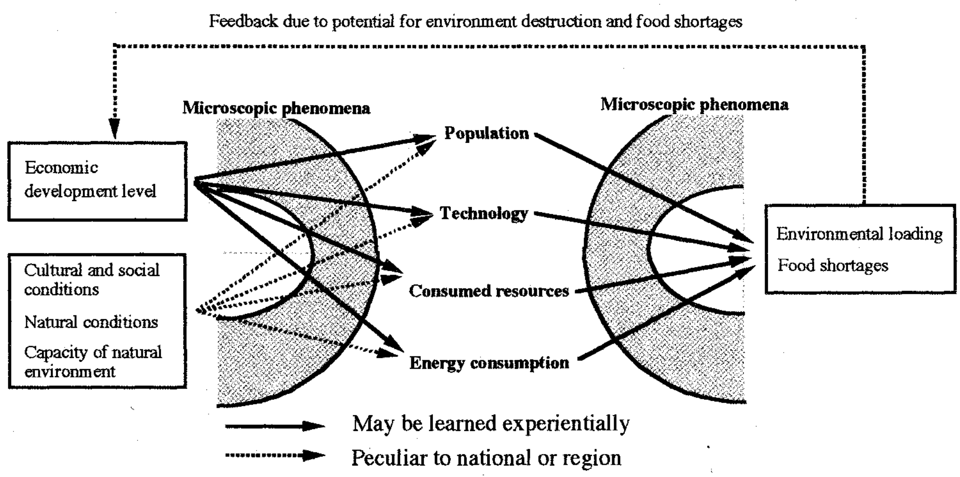

Figure 1. Conceptual diagram

The authors have analyzed the relationship with various environmental indicators using per-capita GDP as a descriptive variable (Kaneko *et al.*, 1996b). GDP/c has been correlated with a variety of economic, social and environmental factors spanning the past 30 years for a total of 24 nations, including several Asian nations and a number of OECD member states, to identify overarching relationships that apply on a global basis.

Adapting the curve which gives the best coefficient among linear, logarithmic , exponential, and logistic relationships, we obtained regression curves of 22 factors with a determination coefficient of 0.8 or above as shown in Table 1. This paper will refer these empirical equations as "learning curves". Fig. 2 and 3 present examples of these learning curves illustrating agricultural shares as a percentage of GDP and average life expectancy. The common trend

Table 1. Summary of learning curves

Category	No.	Item	R^2	Number of data	Number of countries	Equation of Regressional Curve
Economic Structure	1	Share of GDP (Service)	0.86	279	16	$Y=7.22\times LN(X)+66.82$
	2	Share of GDP (Agriculture)	0.84	298	17	$Y=1.98\times 10^{-2}/(1-\exp(-5.53\times 10^{-4}-9.99\times 10^{-3}\times X))$
Sanitation	1	Total Fertility Rate	0.81	127	18	$Y=1.52\times X^{-0.27}$
	2	Infant Motality Rate	0.80	224	19	$Y=11.86\times X^{-0.41}$
	3	Crude Birth Rate	0.82	162	23	$Y=-6.66\times Ln(X)+9.52$
	4	Life Expectancy at Birth	0.87	254	23	$Y=5.20\times Ln(X)+79.22$
	5	Population per hospital bed	0.87	82	22	$Y=59.55\times X^{-0.63}$
	6	Population per nurse	0.82	137	24	$Y=98.06\times X^{-0.71}$
	7	Population per physician	0.83	147	22	$Y=232.37\times X^{-0.82}$
Urbanization	1	Urban Population	0.86	610	21	$Y=14.91\times Ln(X)+92.97$
	2	Passenger Cars per capita	0.90	601	24	$Y=0.939\times X^{1.30}$
Media	1	Households without Electricity	0.94	19	18	$Y=-23.27\times Ln(X)-18.36$, $Y=0$ $(X>0.45)$
	2	Literacy - Adult Female	0.84	21	12	$Y=14.78\times Ln(X)+110.84$, $Y=100$ $(X>0.47)$
	3	Television Receivers	0.92	73	24	$Y=0.879\times X^{0.83}$
	4	Radio Recievers	0.85	67	22	$Y=1.21\times X^{0.58}$
Energy	1	Energy (Grand Total)	0.86	632	24	$Y=5.53\times X^{0.80}$
	2	Energy (Industry Sector)	0.84	632	24	$Y=1.93\times X^{0.82}$
	3	Energy (Total Transport Sector)	0.86	623	24	$Y=1.36\times X^{0.81}$
	4	Energy (Air Transportation)	0.84	464	19	$Y=0.278\times X^{0.95}$
	5	Energy (Road Transportation)	0.85	503	21	$Y=0.889\times X^{0.80}$
Food	1	Calories per capita per day (grand total)	0.81	737	23	$Y=310.37\times Ln(X)+3609$
	2	Calories per capita per day (animal products)	0.88	684	21	$Y=1913\times X^{0.57}$

note: X=GDP/30,000(con. 87 US$) in the equations of regressional curves
source: Kaneko *et al.*, 1996b

seen in many learning curves is rapid change with economic growth up to about the US$5,000 level, and convergence to a particular value thereafter. However, some factors such as motor vehicle ownership are increasing more rapidly than GDP growth, and for which no convergence value can be found.

3. Environmental Forecast for Asia

3.1 Analytical Framework: Subject Nations and Assumptions About Per-Capita GDP

Subject nations for this study consist of seven representative nations in Asia classified by income levels, as shown in Table 2. The time period is from the present to 2050. An economic growth scenario shown in Table 3 is set by assigning each country an exogenous value determined in reference to forecast values in relevant studies (Japan Science & Technology Agency, 1992; World Bank, 1995). Economic growth might impose greater environmental loads and precipitate shortages of food and natural resources, which in turn might tend to limit economic growth. The present study does not explicitly incorporate such negative feedback. However, by devising scenarios that tend to slow the speed of future economic growth, it is possible to incorporate such an outcome. In order to assure the feasibility of selected learning curves, calculated values of each factor during 1960 to 1993 are compared with actual ones. When the differences between the both are significant, parameters of the formulas or formulas themselves are substituted with other ones to attain better correspondence.

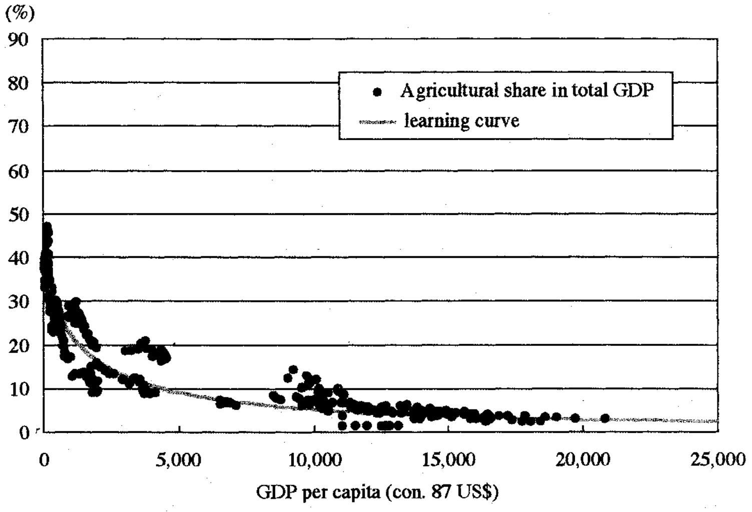

Figure 2. Share of agricultural with total industry GDP

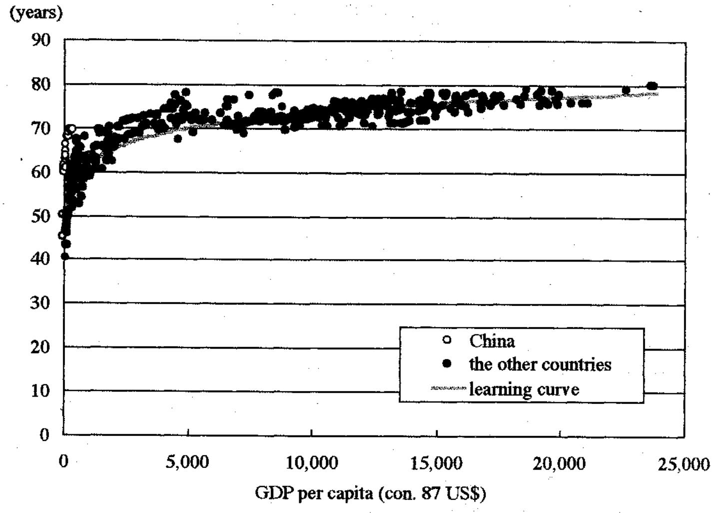

Figure 3. Life expectancy

Table 2. Target nations

Type	Nations (per capita GDP in parenyheses, 1987 US$)
Low-income nations	China (367), India (386)
Medium-income nations	Indonesia (595), Philippines (610), Thailand (1,565)
High-income nations	Korea (4,859), Malaysia (2,749)

Table 3. Economic growth rate (%)

	China	India	Korea	Other
1993-2000	8.0	5.4	6.6	7.0
2000-2025	7.0	5.4	4.0	5.0
2025-2050	5.0	3.4	2.0	3.0

3.2 Urban and Rural GDP

The simplest way for forecasting is to obtain future values using the learning curve by assigning a future GDP/c. This method can be applied to factors that have a universal relationship with GDP/c. However, there are many factors that cannot simply be forecasted by this way. In this case, establishing a forecasting frame is needed by the combination of the individual learning curve to describe the relationship between different factors.

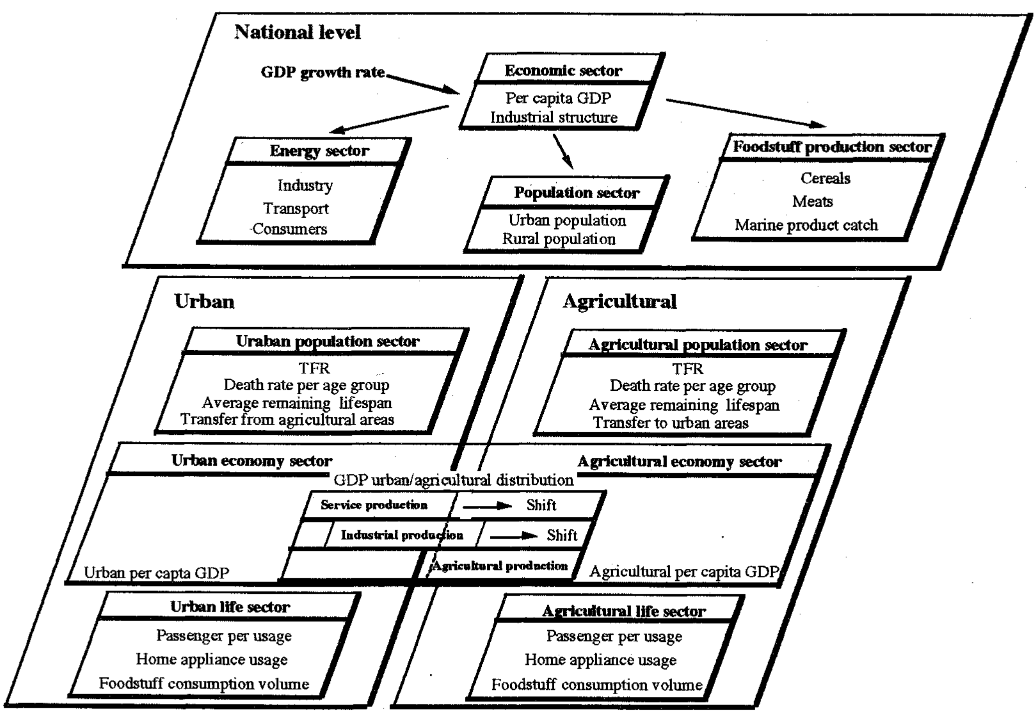

Figure 4. Basic model structure

The forecasting methodology employed in this paper posits a chain structure (system dynamic) linking various factors *via* empirical equations based on learning curves. Large income differentials between urban and rural areas is here taken into account. This income gaps result in big differences in standards of living as expressed in terms of factors ranging from family forms to energy consumption and culinary habits. In order to consider the urban-rural differences in the process of economic growth, the forecasts are split into two separate forecasting frames for each country: an urban frame and a rural frame. In other words, the urban and rural forecasting frames are treated as having separate applicable learning curves for the respective income levels, with the sum of the two serving as the value for the nation as a whole. Fig. 4 presents the forecasting frames. Table 4 lists the learning curves and the descriptive variables used in forecasting.

Table 4. Target indices and explanatory variables

Sector	*Target indices*	*Explanatory variables*		
Economy	Per capita GDP	GDP	Population	
	Agricultural production	Industry breakdown ratio	GDP	
	Industrial production	Industry breakdown ratio	GDP	
	Services production	Industry breakdown ratio	GDP	
	Industry breakdown ratio	Per capita GDP		
	Urban per capita GDP	Industrial production	Services production	
	Agricultural per capita GDP	Agricultural production	Industrial production	Services production
Population	Total population	Mean lifespan	TFR	
	Mean lifespan	Per capita GDP		
	TFR	Per capita GDP		
	Population movement	Urban per capita GDP	Agricultural per capita GDP	
Foodstuff demand	Total per capita foodstuff consumption	Per capita GDP		
	Total per capita animal foodstuff consumption	Per capita GDP		
	Total per capita plant foodstuff consumption	Total per capita foodstuff consumption	Total per capita animal foodstuff consumption	
	Total per capita cereal consumption	Total per capita plant foodstuff consumption	Cereal within plant foodstuff	
	Cereal within plant foodstuff	Per capita GDP		
	Foodstuff cereal consumption	Foodstuff cereal consumption	Livestock feed cereal consumption	
	Total cereal consumption	Total per capita cereal consumption	population	
	Livestock feed cereal consumption	Meat consumption	Cereal source unit	
	Meat consumption	Per capita meat consumption	population	
	Per capita plant foodstuff consumption	Total per capita animal foodstuff consumption	Meat within total animal foodstuff	
	Meat within total animal foodstuff	Per capita GDP		
Foodstuff production	Cereal production	Harvest	Cropland area	
	Harvest	Input fertilizer	Tractors in use per capita agricultural population	Irrigation ratio
	Input fertilizer	Per capita GDP		
	Tractors in use per capita agricultural population	Per capita GDP		
	Irrigation ratio	Per capita GDP		
	Cropland area	Cultivated area	Cropland breakdown by crop	
	Cultivated area	Agricultural land		
	Cropland breakdown by crop	Time (years)		
	Agricultural land	Urban land	Forest	
	Urban land	Time (years)		
	Forest	Time (years)		

There are, however, pragmatic difficulties in using a single universal definition to divide countries into urban and rural (non-urban) realms. The United Nations once defined an urban area as an administrative district with a minimum of 20,000 residents, but it has switched to using the definitions made by individual member state instead. The first reason for this is that member states use sometimes arbitrary methods of setting administrative unit boundaries, which means there is no universally applicable standard for unit size. The second reason is that non-population related conditions that make an area urban or rural differ from one country to another, which renders it difficult to impose minimum population of 20,000 as an external criterion (Kono, 1986). These create problems in terms of how to handle statistics for urban and rural areas that are based on this multiplicity of divergent definitions.

In this paper, the delineation between urban and rural in Fig. 4 is expediently made as follows. First, nationwide GDP is calculated using nation-specific economic growth rates, and is divided by population to yield national average GDP/c. The share of agricultural, service, and industrial production are calculated using learning curves expressed in the form of eqs (1)

, (2) and (3) below. Fig. 5 illustrates their relationship.

$$F(\sigma) = \begin{cases} -8.819\ln(\sigma) + 82.416, & for \quad 0 \leq \sigma \leq 3321 \\ -4.696\ln(\sigma) + 48.979, & for \quad 3221 < \sigma \leq 18791 \\ 1.979/\{1 - \exp(0.00559 - 0.000067\sigma)\}, & for \quad 18791 < \sigma \end{cases} \qquad (1)$$

$$S(\sigma) = \begin{cases} 7.698\ln(\sigma) - 10.503, & for \quad 0 \leq \sigma \leq 14121 \\ 69.40/\{1 + \exp(-0.1355 - 0.000153\sigma)\}, & for \quad 14121 < \sigma \end{cases} \qquad (2)$$

$$I(\sigma) = 100 - F(\sigma) - S(\sigma) \qquad (3)$$

where, $F(\sigma)$, $S(\sigma)$, $I(\sigma)$ are shares of agriculture, service and industry with total GDP, respectively; and σ is per capita GDP in constant 1987 US$ price.

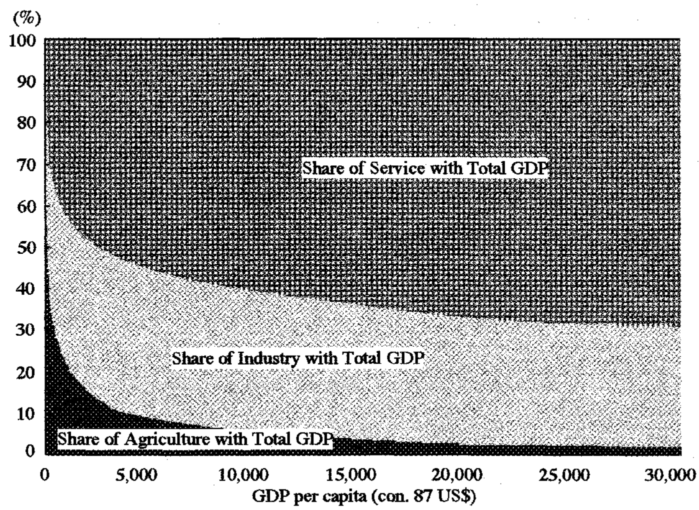

Figure 5. Changes in per capita

Separate GDP figures for urban and rural areas are calculated in order to calculate GDP/c values for each. First, all agricultural and service production are allocated to rural and urban income, respectively. The distribution ratios for industrial production between urban and rural areas is determined taking into account the past progression of urbanization (*i.e.*, the proportion of urban population out of total national population) and GDP/c for each nation. These distribution rates, therefore, differ between countries. Countries such as China retain fairly large rural societies with differentials from urban areas in living standards and income levels. Those like South Korea are shrinking rural-urban differentials. Then, GDP/c in the urban and rural areas are obtained, using actual population of the both. Next, the population in the both areas during 1960 to 1993 are calculated as mentioned in the next section and compared with actual ones. In order to minimize the difference between calculated and actual population during the period, the distribution ratio of service and industry productions and parameters of formulas are modified, and social movement is assumed as well. When appropriate formulas are obtained, the future urban and rural population in the individual countries are calculated.

3.3 Forecasting Urban Population

Population growth is determined by natural and social growth. Factors influencing natural growth include the birth rate, the death rate, and average life expectancy. In general, higher standards of living are accompanied by improved medical technology and sanitary conditions. As living standards improve, women's educational attainment increases, and this promotes a more active social role for women. At the same time, educational costs per child increase. Then, the number of children women bear per lifetime (total fertility rate, or TFR) declines. While it is impossible to plot a learning curve between economic growth (GDP/c) and population per se, universal relationships can be observed between various factors that determine population and GDP/c. Consequently, urban population represents an appropriate target for system dynamics-based forecasting, in which various learning curves are integrated.

Average life expectancy explained by higher living standards (GDP/c) is determined by using the learning curve. Death rates are calculated for each age group from average life expectancy figures. TFR is also calculated from the learning curve, although TFR is highly sensitive to national conditions. The Asian region, particularly when limited to areas with GDP/c of under $5,000, exhibits differences in TFR trends due to local circumstances in particular countries, such as the one child policy adopted in China. Therefore, statistical values for each nation are examined, and nations are divided into several groups before deriving learning curves.

Fig. 6 presents a diagram of the population forecasting model based on these assumptions. Population is calculated by dividing total population into four age groups according to the UN categorization and making a balance between input and output for each age group. For example, the 15-44 age group increases each year by one-fifteenth the size of the previous year's 0-14 age group. Similarly, one-thirtieth of the previous year's 15-44 age group passes on to the next age group. Furthermore, age group sizes decline as a result of death. The current year's population can be calculated by calculating the increases and decreases *vis a vis* the year before. Each age group is subject to societal movement independent of the balance described above that act to increase urban populations and decrease rural populations.

The number of live births NB is calculated according to the following formula, with the number of child-bearing years assumed to be 30:

$$NB = PF * TFR/Y \tag{4}$$

where PF is previous year female population of child-bearing age (*i.e.*, one half the total population of age 15-44) , and Y number of child-bearing capable years.

When the nation as a whole is divided into urban and rural areas, as in the current study, the primary determinant of social growth of population is the income differential. Societal movement occurs as people move from rural to urban areas seeking more income and a better life. In this study, the subject groups for these movements are assumed as adult age groups (age 15-65) and their children. Because it is unable to obtain actual data on urban and rural GDP/c or on population movement from rural to urban areas, the amount is adjusted accounting for total population and urbanization rate of each country. In doing so, the data from ESCAP (Japan Environmental Agency, 1993) are used as reference values. Table 5 lists the urban and rural GDP/c, urban-rural income differentials, and size of societal movements calculated in this manner.

Table 5. Urban-rural income differentials and social movements

Nation	Year	GDP/capita(US$) Nation mean	City	Rural	GDP/c gap (US$)	Capital transfer (million)	Population (million)	Urbanization ration (%) Calculated	Actual
China									
	1960	76	216	43	5.0	1.9	657.5	19.0	18.7
	1970	118	340	62	5.5	4.4	814.9	20.0	17.7
	1980	185	502	91	5.5	5.3	997.7	22.7	19.9
	1990	309	775	143	5.4	5.5	1143.6	26.4	33.5
	2000	579	1,350	239	5.7	7.4	1274.1	30.6	
	2010	1,038	2,220	383	5.8	8.6	1398.4	35.7	
	2020	1,889	3,703	605	6.1	11.0	1511.1	41.5	
	2030	3,178	5,618	891	6.3	11.7	1608.0	48.4	
	2040	4,933	8,000	1,324	6.0	8.9	1687.3	54.1	
	2050	7,755	11,868	1,930	6.2	9.0	1748.4	58.6	
India									
	1960	206	612	117	5.2	3.9	442.3	18.0	18.0
	1970	287	763	158	4.8	4.2	569.5	21.3	19.8
	1980	409	1,027	212	4.8	5.2	715.0	24.1	23.1
	1990	607	1,460	281	5.2	6.6	862.0	27.7	27.3
	2000	902	2,054	335	6.1	9.6	998.7	33.0	
	2010	1,362	2,733	438	6.2	10.0	1119.0	40.3	
	2020	2,143	3,845	603	6.4	10.0	1203.3	47.5	
	2030	3,160	5,079	800	6.4	8.9	1254.6	55.2	
	2040	4,295	6,317	1,079	5.9	6.7	1289.6	61.4	
	2050	5,878	8,153	1,428	5.7	5.8	1316.4	66.2	
Indonesia									
	1960	190	673	108	6.3	0.5	96.2	14.6	14.6
	1970	259	810	143	5.6	0.8	121.2	17.3	17.1
	1980	356	926	196	4.7	1.4	151.4	21.9	22.2
	1990	509	1,059	285	3.7	1.9	181.5	29.0	31.6
	2000	846	1,533	456	3.4	1.8	206.2	36.2	
	2010	1,268	2,093	635	3.3	1.8	224.2	43.4	
	2020	1,952	3,107	761	4.1	1.8	237.2	50.8	
	2030	2,780	4,115	963	4.3	1.5	246.4	57.6	
	2040	3,646	5,027	1,213	4.1	1.4	252.5	63.8	
	2050	4,809	6,206	1,657	3.7	1.2	257.3	69.3	
Korea									
	1960	520	1,364	196	7.0	0.4	25.0	27.7	27.7
	1970	922	1,717	352	4.9	0.7	32.9	41.8	40.7
	1980	1,805	2,586	707	3.7	0.7	39.3	58.4	56.9
	1990	3,833	4,845	1,354	3.6	0.5	43.2	71.0	71.8
	2000	7,270	8,476	2,572	3.3	0.2	45.9	79.6	
	2010	10,489	11,695	3,822	3.1	0.1	48.0	84.7	
	2020	15,248	16,462	6,780	2.4	0.0	49.8	87.5	
	2030	20,194	21,148	12,896	1.6	0.0	51.5	88.4	
	2040	24,419	25,482	15,874	1.6	0.0	53.0	88.9	
	2050	29,634	30,842	19,524	1.6	0.0	54.3	89.3	
Malaysia									
	1960	708	1,899	306	6.2	0.1	8.1	25.2	25.2
	1970	1,036	2,176	456	4.8	0.1	10.8	33.7	27.0
	1980	1,540	2,939	652	4.5	0.1	14.2	38.8	34.7
	1990	2,387	4,295	930	4.6	0.1	17.9	43.3	43.6
	2000	3,923	6,717	1,341	5.0	0.2	21.3	48.0	
	2010	5,619	9,029	1,765	5.1	0.2	24.3	53.1	
	2020	8,304	12,561	2,067	6.1	0.3	26.7	59.4	
	2030	11,470	15,722	2,692	5.8	0.2	28.6	67.4	
	2040	14,776	19,008	3,367	5.6	0.2	29.9	72.9	
	2050	19,446	23,862	4,302	5.5	0.1	30.5	77.4	
Philippines									
	1960	418	715	290	2.5	0.4	27.6	30.3	30.3
	1970	447	659	331	2.0	0.5	37.6	35.4	33.0
	1980	492	666	381	1.7	0.5	49.9	39.1	37.4
	1990	571	727	455	1.6	0.5	62.8	42.6	43.8
	2000	897	1,099	706	1.6	0.5	71.8	48.6	
	2010	1,342	1,624	985	1.6	0.5	78.2	55.9	
	2020	2,024	2,431	1,317	1.8	0.5	84.5	63.4	
	2030	2,790	3,196	1,830	1.7	0.4	90.7	70.3	
	2040	3,515	3,847	2,505	1.5	0.3	96.7	75.2	
	2050	4,445	4,714	3,456	1.4	0.2	102.8	78.6	
Thailand									
	1960	300	1,045	194	5.4	0.2	26.4	12.5	12.5
	1970	454	1,353	290	4.7	0.2	36.4	15.5	13.3
	1980	734	1,943	459	4.2	0.3	47.2	18.5	17.3
	1990	1,294	3,006	795	3.8	0.4	55.9	22.6	22.8
	2000	2,380	4,776	1,450	3.3	0.4	60.9	28.0	
	2010	3,720	6,420	2,332	2.8	0.4	63.4	34.0	
	2020	5,860	8,949	3,846	2.3	0.3	65.6	39.5	
	2030	8,430	11,708	5,799	2.0	0.3	67.5	44.5	
	2040	11,080	14,309	7,968	1.8	0.3	69.0	49.1	
	2050	14,602	17,804	10,974	1.6	0.2	70.4	53.1	

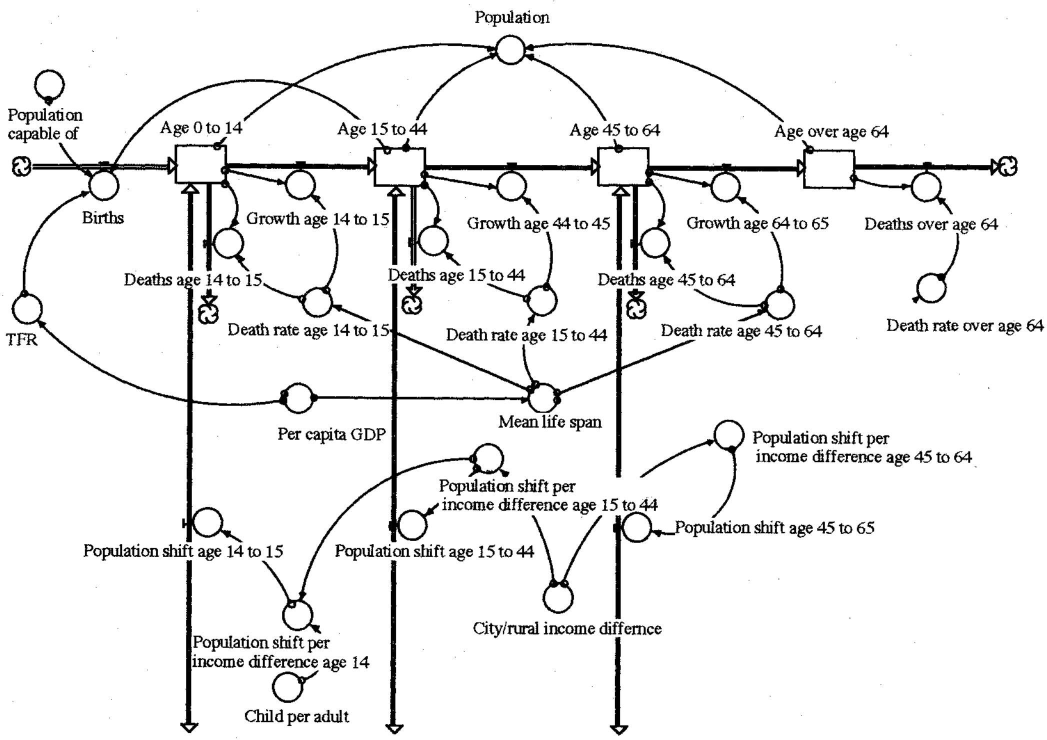

Figure 6. Population sector model

Fig. 7 presents the population forecasts based on these calculations. Rapid growth in urban population occurs due to social growth. In every nation except South Korea, where the urban population already exceeds the rural population, the urban population is forecasted to overtake and surpass the rural population in the near future. This will happen faster in the Philippines and Malaysia, and somewhat more slowly in Thailand and China. It is projected that agriculture in Thailand and China will remain somewhat large and will decline at a comparatively leisurely pace compared to other countries. High economic growth rates in all these countries will likely reduce total population growth rates. National populations projected by this study for 2025 largely accord with previous forecasts (United Nations, 1993; World Bank, 1994).

4. Food Demand and Supply Forecasting

4.1 Food Consumption

Here, the method is applied for forecasting food demand and supply. The definition of food in this study is limited to cereals (*i.e.*, rice, wheat, barley, corn, and other miscellaneous cereals). Higher standards of living produce both quantitative and qualitative changes in culinary habits. Fig. 8 presents learning curves on the relationship between per-capita and per-day consumption of all foods and of animal foods on a calorie basis and GDP/c. Nations in Asia could be divided into two groups in which similar national learning curves on animal

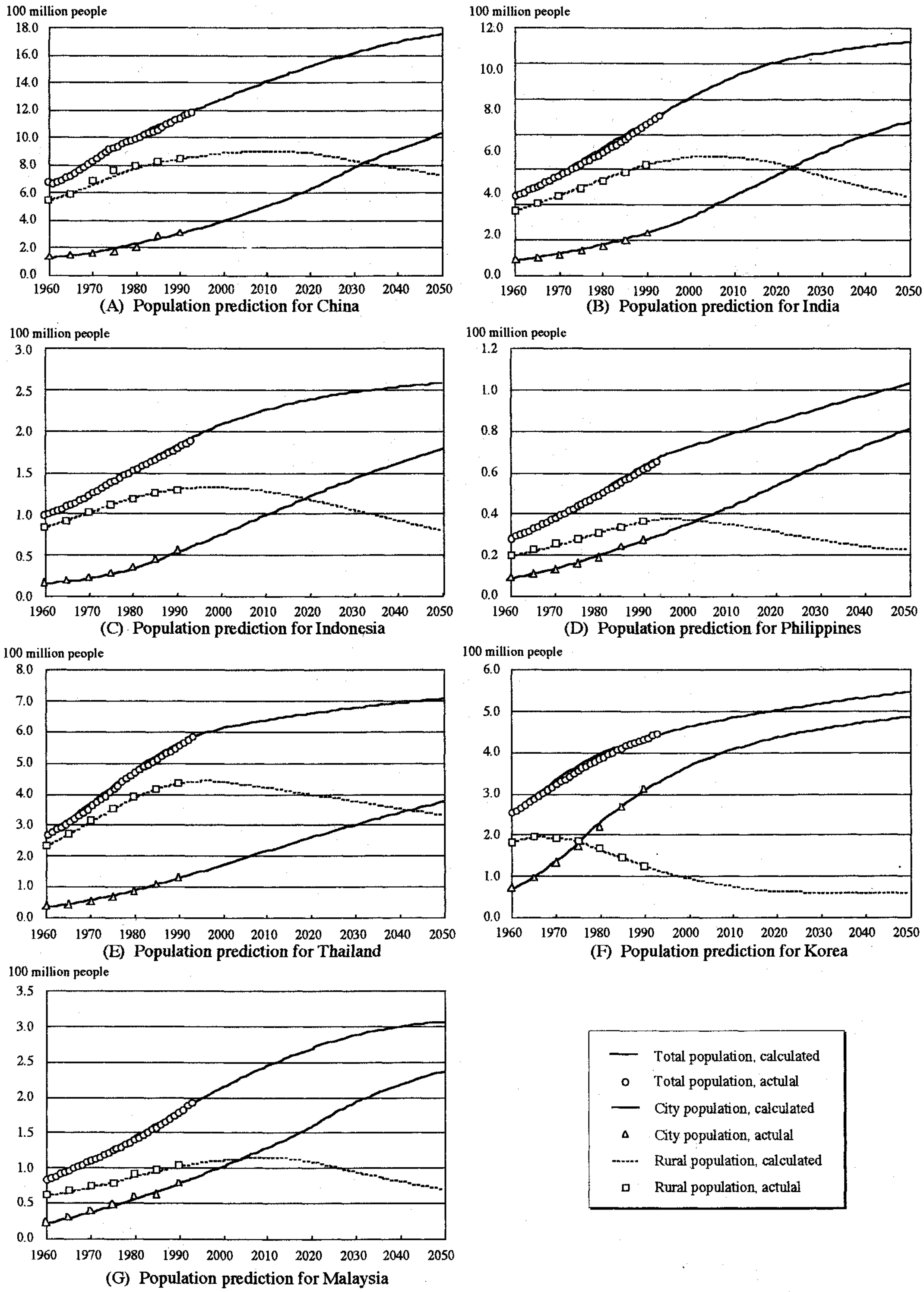

Figure 7. Population predictions

food consumption are found. Group I includes China, India, the Philippines, and Malaysia, while Group II includes Indonesia, South Korea, and Thailand.

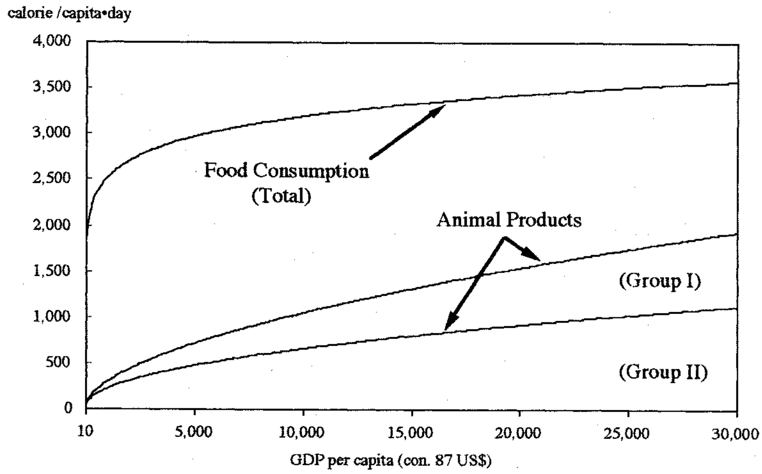

Figure 8. Total calorie and animal foodstuff calorie consumption

When population forecast is made, the learning curves in Fig. 8 can be used to forecast total food consumption. Determining consumption levels of meat (*i.e.*, animal food), demand of feed cereals for the meat production is obtained. In this study, forecast of food consumption (cereal consumption) is conducted based on population, total food consumption and animal food consumption. The macroscopic relationship between GDP/c and food consumption already includes the microscopic factor of cereal consumption such as culinary habits or availability of food. Fig. 9 presents a flowchart of food consumption forecasting. Consumption of plant and animal foods is expressed on a calorie basis derived from the learning curve on GDP/c and food consumption.

Fig. 10 shows learning curves derived for each country on the relationship between GDP/c and the percentage of cereal consumption out of total plant food consumption. The results show that rising living standards lead to diversification of culinary habits and reduced intake of cereals as primary food. In developed countries the ratio of plant food calorie intake to total calorie intake ranges from 30% to 50%. Using this ratio and total plant food calorie consumption, cereal calorie consumption can be calculated. Then a weight conversion is made of this calorie consumption in order to calculate the weight of cereal consumed.

With respect to indirect cereal consumption in the form of feed cereals, forecast is made on meat calorie consumption from the percentage of meat in total animal food consumption. A weight conversion is made of that meat calorie consumption to yield the feed cereal required to produce that quantity of meat. This makes it possible to forecast feed cereal consumption in relation to livestock raising patterns in each country. This analysis relies on food supply and demand tables for leading nations of the world (FAO, 1991) to obtain the calorie-weight conversion coefficient, percentages of meat in total animal food consumption, and feed cereal required for meat production.

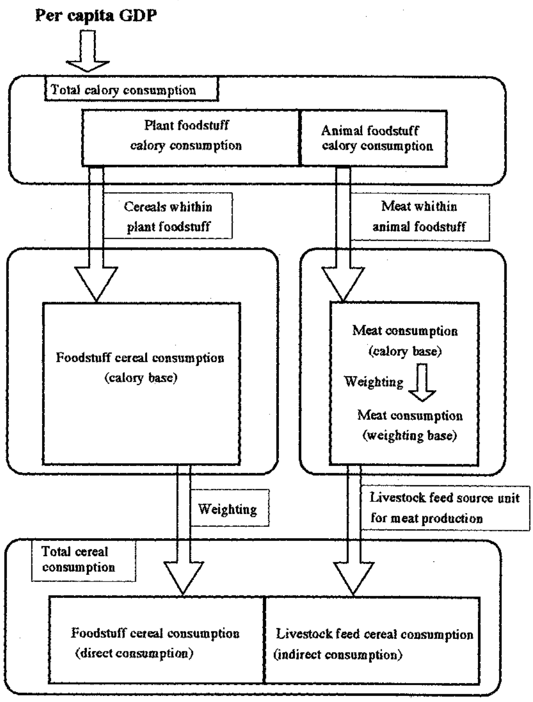

Figure 9. Cereals within plant foodstuff

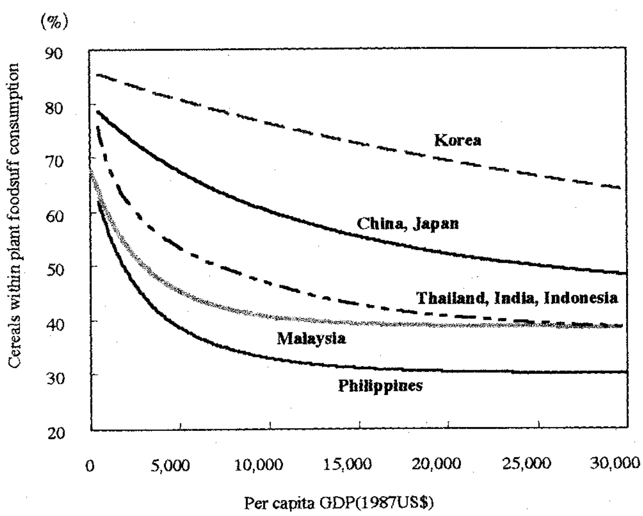

Figure 10. Cereals within plant foodstuff consumption

4.2 Food Production

Crop land area and crop yield determine agricultural production. Crop land area varies not only according to the crop mix, which differs greatly from one country to another, but also according to local land use and agricultural policy. This makes it difficult to formulate a universally applicable model based on the top-down approach. Therefore, the crop mix of seven agricultural products (including the five cereal categories of rice, wheat, barley, corn, and miscellaneous cereals plus legumes and tubers) is calculated through a diachronic regression analysis by country and crop land area. Total crop land area is forecasted presuming that it changes at the same rate as changes in total arable.

It is well known that food crop yield (harvest per unit of land area) improves spectacularly if land is cultivated more intensively (by utilizing fertilizers, pesticides, energy inputs, and agricultural machinery). Moreover, the degree of land intensiveness empirically correlates with GDP/c. This macroscopic correlation makes it possible to forecast crop yield as a result. In this study, the following factors are selected as descriptive variables for crop yield: volume of fertilizer applied, number of tractors used per-capita of rural population, and irrigation rate, which serve as indicators of the degree of land intensiveness. However, the relationship between these factors and crop yield is synergetic, and individual factors cannot be considered separately. Therefore, a logistic-type weighted regression curve is applied to derive the crop yield forecast curve. Maximum limit values in the curves are set based on the following three scenarios according to future crop yield increases until 2050 considering the past crop yield growth in the last 30 years:

Scenario 1: 100% growth
Scenario 2: 50% growth
Scenario 3: 20% growth

4.3 Food Supply-Demand Balance

Table 6 lists the forecasts of cereal supply-demand balance for each country under the three scenario mentioned above. The results indicate that each of countries except for Thailand may cease to be self-sufficient in cereal early in the next century, as has already happened with Japan and South Korea. Roughly 100 million tons of cereal will have to be imported annually to meet their demand in the first half of the next century. India and Indonesia retain some chance of achieving self-sufficiency in cereal even if they maintain current rates of economic growth, depending on agricultural land policies and how much crop yield improvement they can realize.

In the second half of the next century, China will determine cereal supply-demand balance for the region as a whole. Fig. 11 presents forecasts of Chinese cereal consumption and production. According to Scenarios 1, 2 and 3, these forecasts project that demand for cereal in China will exceed supply in the years 2008, 2001, and 1996, respectively. Recent high-profile reports from the World Watch Institute and the Overseas Economic Cooperation Fund (Brown, 1995; Tsuji, 1995) have both predicted that China will cease to be able to meet its own cereal needs by 2010 (Table 7), while these forecasts are based on very different methodologies. A comparison of them is presented in Table 8. The World Watch Institute's forecast is based on an extremely simplistic model, and its results show definite influence from intuitive parameter definitions based on widely-shared knowledge.

The OECF (Overseas Economic Cooperation Fund) forecast is based on a thorough analysis of data collected in separate provincial-level surveys. Both reports rely on straight-line extrapolations from average past growth rates, and their long-term forecasts might require

Table 6. Demand forecasts for cereals

	Scenario	1990	2000	2025	2050
China	1	30,520	37,170	▲89,526	▲139,781
	2	28,727	424	▲181,685	▲239,551
	3	25,972	▲33,170	▲240,034	▲299,916
India	1	23,402	29,303	33,691	57,218
	2	20,770	18,148	▲2,317	▲11,459
	3	18,213	8,049	▲26,273	▲16,374
Indonesia	1	8,625	12,225	13,785	18,786
	2	7,698	5,833	▲950	▲2,218
	3	6,820	420	▲10,884	▲8,806
Korea	1	▲2,109	▲4,495	▲11,294	▲17,767
	2	▲2,648	▲5,208	▲11,965	▲18,381
	3	▲3,164	▲5,861	▲12,577	▲18,941
Malaysia	1	▲2,158	▲3,209	▲6,559	▲10,002
	2	▲2,152	▲3,295	▲6,876	▲10,392
	3	▲1,937	▲3,261	▲7,083	▲10,639
Philippines	1	5,032	7,643	5,180	3,148
	2	4,975	4,287	330	▲1,763
	3	4,899	2,834	▲2,592	▲4,712
Thailand	1	14,985	15,879	14,997	12,991
	2	13,406	13,568	12,445	10,426
	3	12,008	11,919	10,912	8,886

(▲ indicates minus (excess demand))

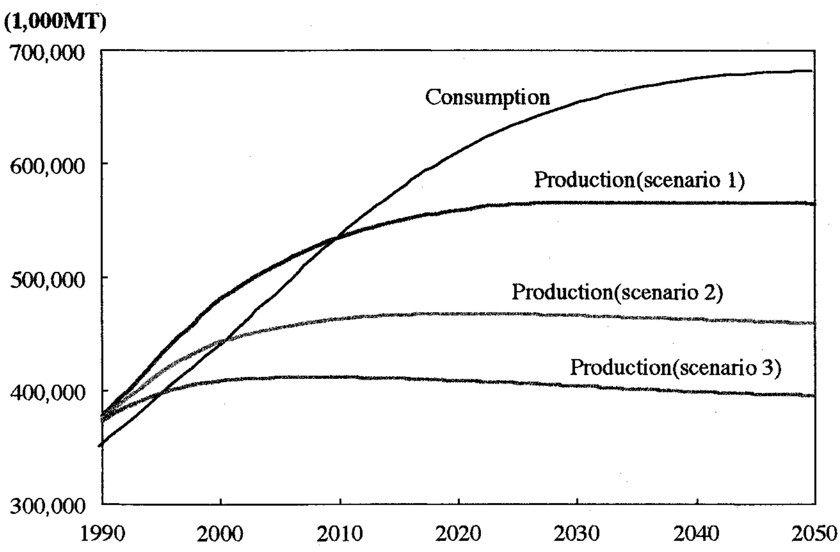

Figure 11. Cereal consumption and production forecasts for China

Table 7. Comparison of supply and demand forecasts for China (1000MT)

	1993	2000	2005	2010
Scenario 1	33,251	37,170	16,505	▲12,312
Scenario 2	25,689	424	▲38,141	▲81,195
Scenario 3	15,161	▲33,170	▲81,249	▲130,750
Comparison: OECF	24,420	▲203,840	▲69,060	▲136,310
Comparison: WWI	▲28,000	▲81,000	▲118,000	▲156,000

(▲ indicates minus (excess demand))

argument. In contrast, this study implies somewhat more optimistic prospects for the food supply-demand balance than either of the two previous reports, mainly because the present approach posits a substantial decline in consumption of cereal as a primary food due to changes in culinary habits, and because continued growth in crop yield is assumed.

4.4 Possible Improvements to the Forecasting Model

If the food supply-demand balance goes into deficit due to weather, particularly in a country like China or India, it can impact food demand worldwide. Therefore, if a real food shortage situation occurs, the governments likely take whatever steps they could to deal with it. They will probably respond by expanding crop land area the year after a poor harvest and by storing cereal during the years when the cereal demand-supply balance is in surplus for the next time of food shortage.

A calculation for China based on the assumptions regarding this experimental modification is presented below. The dispersion of actual cereal production totals (from 1960 through 1990) relative to the cereal production totals calculated from the basic model is approximately 21 million tons. It is assumed that variation occurs with a normal distribution of mean 0 and dispersion σ, *i.e.*, $N(0, \sigma)$, due to the effects of weather, occurs around the path of the cereal production from the basic model.

Table 8. Conparision of Models

	Methods	Foodstuff consumption		Foodstuff production	
		Population	Per capita consumption	Cropland	Harvest
World Watch Institute	Simple forecast calculated as (population) x (per capita consumption) = (foodstuff production).	Mid-range forecast of the International Survey Center of the United States Department of the Census (1993)	Total per capita annual cereal consumption calculated for three scenarios: 290, 350 and 400kg.	All factors taken into account, and rapid industrialization assumed to continue. Cropland assumed to decrease by at least 20% (0.5% per annum) between 1990 and 2030, which means current production will decrease linearly.	
OECF	Forecasts extended temporally by past average growth rates. Totals achieved by addition of regional sub-totals. Five cereal categories are predicted: rice, wheat, corn, soya beans and other. Consumption is classified by primary foodstuff, livestock feed and processed foodstuff, with forecasting based on income elasticity and regional GDP.	Population growth ratio determined from the 1982 and 1990 censuses, and adjusted (population movement in - population movement out).	(1) calculated separately for usage by primary foodstuff, livestock feed and processed foodstuff, and (2) changes over 14 years in national per capita GDP and per capital consumption used to calculate four income elasticity values for various per capita consumption levels. Allocation to regions based on per capita consumption by region in 1993.	(1) cereals which have been increasing for the past decade will stop increasing and maintain present (1991-1993) levels, and (2) cereals which have been decreasing for past decade will continue to decrease at the same rate.	(1) The growth rate of the past decade will be maintained, and (2) upper limits are set for each crop, with that level of production maintained after the crop reaches the upper limit.
The Present Study	System dynamics model, based on the learning curve using GDP/c as the explanatory variable. Population and foodstuff consumption were forecast based on two submodels (urban and farming village). Foodstuff production was calculated for seven categories, and cereal production broken down into direct consumption, and indirect consumption in the form of livestock feed to produce consumed meat.	The models for the urban and village populations are assembled based on the TFR, average lifespan and death rate learning curves, and coupled through the social movement generated by the income difference between them.	Forecasts for urban and village based on learning curves for GDP/c and calory-based total foodstuff consumption and animal foodstuff consumption. Direct consumption of cereals forecast from plant foodstuff consumption. Animal foodstuff consumption used to forecast meat consumption, and indirect consumption through livestock feed.	Breakdown of land usage estimated recursively over time and forecast total cereal cropland area. Breakdown of this cropland area for seven cereals estimated recursively over time to forecast cropland area for each crop.	For the increase in GDP/C and harvests from 1960 to 1993, factors indicating land concentration degree (fertilizer input, tractors, irrigation ratio) were used as explanatory variables for the harvest increase, along with logistics line weighted recursion. The requisite harvest maximum was set at 100%, 50% and 20% of the increase for the past 30 years.

Model A is defined as the version that accounts for policy changes to adjust crop land area in relation to deficits in the cereal supply-demand balance. This model assumes that the adjusted crop land area is equivalent to the cereal shortage of the previous year, but does not exceed the maximum variation during the last decade, *i.e.*, 2.0 million hectares. When a persistent deficit occurs, adjusted crop land area is presumed to continually increase, but the total increase is restricted not to exceed the maximum total crop land area of China which is estimated at 10 million hectares (Wittwer *et al.*, 1989). It is also assumed that crop land adjustments are made each year according only to the previous year's cereal supply-demand balance, irrespective of the previous adjustment history. Such crop land adjustment policies is assumed to be initiated in 1990.

Model B assumes that in years of surplus the surplus portion is put into storage in addition to the land policy assumed in model A.

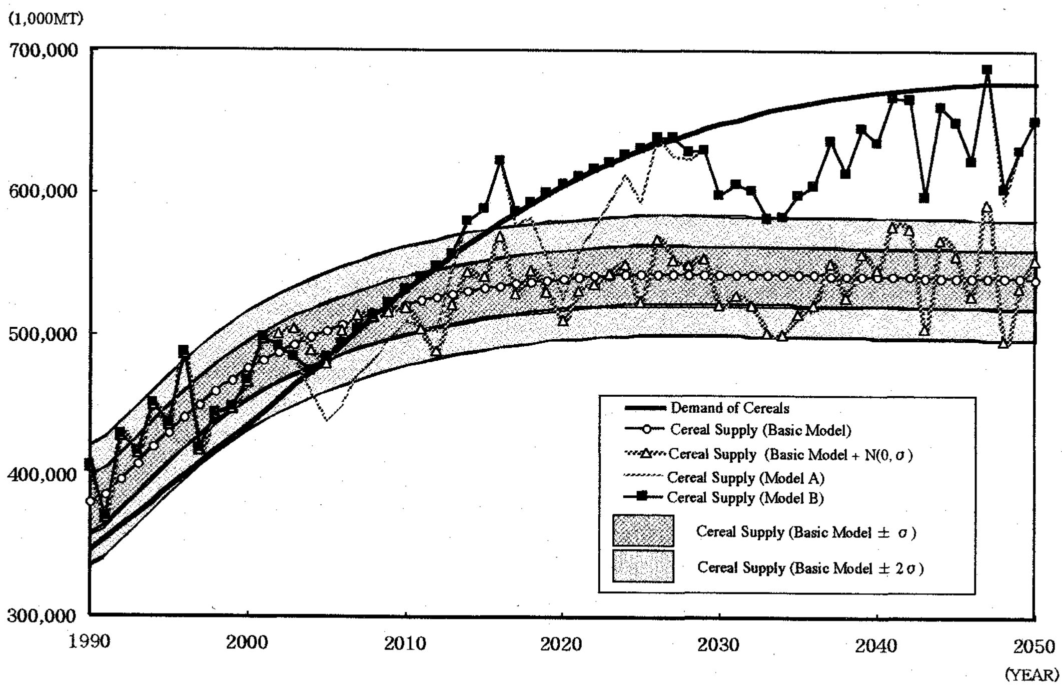

Figure 12. Chinese cereal supply and demand forecasts adjusted for variation in weather and agricultural policy

The results from these two models are shown in Fig. 12. Examination of these results shows that whereas the basic model forecast projects that China will remain self-sufficient in cereal only until 2010, model A projects self-sufficiency to 2017, and model B to 2027. These results stem from highly divergent qualitative assumptions, and have little reliability as forecasts. Nevertheless, we can interpret these results to mean that there is a chance of avoiding or at least easing the effects of a truly serious food shortage under appropriate agricultural policy. This study does not address other forms of uncertainty that affect demand, such as world cereal prices or political situation over food production and export. What the authors wish to point out here is the importance of qualitative factors that have not been incorporated into previous forecasts, such as regional and temporal variations, government policies, and social customs.

5. Conclusions

The results of this study may be summarized as follows: (1) Learning curves are formulated based on past experience in countries around the world describing the relationship between economic growth and industrial structure, population, and food supply and demand; (2) a forecasting method is proposed based on the learning curves mentioned above, and it is applied to forecasting of population and food demand in the Asia-Pacific region; (3) the seven Asian nations examined in this study are likely to experience population growth of 45% by the middle of the next century, with the urban population expected to exceed the rural population; (4) if the current decline in crop land area continues, demand for food cereals in China will outstrip supplies in the near future, even if there are fairly significant increases in crop yield; (5) possibilities of improvements are discussed in the food demand model to account for climatic variations and agricultural policy, serving to indicate one direction for future environmental forecasting model formulation.

This paper presented a methodology of forecasting based on a macroscopic model using learning curves. If we attempt to describe macroscopic phenomena by incorporating more microscopic (semi-macroscopic) mechanisms, more factors would come to the surface. Thus, the next stage would involve formulating a top-down type "semi-macroscopic" model that incorporates a larger number of factors and relationships. Also, there are always a multitude of factors other than the ones identified. It will never be possible to explain everything by referring only to certain factors deemed to be highly relevant. Moreover, if we treat these environmental systems as complex systems, unexpected phenomena and factors could appear.

The authors are in the process of developing methodology for handling uncertainty in forecasting (Kaneko *et al.*, 1996a). The system being developed contains three main components. The first is a top-down type forecasting model. The second is a knowledge database that contains quantitative data serving as the basis for the model along with environmental data in all forms that affect human discernment and reasoning. The third is an inferential system for incorporating quantification of human discernment and reasoning into forecasting. The challenge in the future is to use this system to develop techniques for long-term environmental forecasting at the semi-macroscopic level which can incorporate macroscopic top-down models and microscopic bottom-up models.

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