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This study applies theories of systems and system dynamics to ecological economic systems in the oasis environment, with the intention of finding the basic characteristics of the oasis environment and its feedback structures. This study explores the inner mechanisms of economic development in the oasis environment and its relationship to policy variables. This model is applied to economic development in the Manas oasis of the Xinjiang Uygur Autonomous Region of China. System dynamics method starts from studying feedback structure within the system study and then searches for the best solution through identifying the right "policy point" and through model simulation in the computer. It embodies the cream of "systems cybernetics theory". This study is justified because the nature of the oasis system and the simulation results are scientifically sound and practically feasible.

An oases dynamics model and its application in the Manas oasis CHEN Zhengjiang1, SHI Wenzhong2, HUI Yanghe1 (1. Dept. of Urban and Resource, Northwest University, Xi´an 710069, China; 2. Dept. of Land Survey and Geo-information, The Hong Kong Polytechnic University, Hong Kong, China) Abstract: This study applies theories of systems and system dynamics to ecological economic systems in the oasis environment, with the intention of finding the basic characteristics of the oasis environment and its feedback structures. This study explores the inner mechanisms of economic development in the oasis environment and its relationship to policy variables. This model is applied to economic development in the Manas oasis of the Xinjiang Uygur Autonomous Region of China. System dynamics method starts from studying feedback structure within the system study and then searches for the best solution through identifying the right "policy point" and through model simulation in the computer. It embodies the cream of "systems cybernetics theory". This study is justified because the nature of the oasis system and the simulation results are scientifically sound and practically feasible. Key words: oasis; dynamic modeling; Manas oasis CLC number: P901 In the late 1950s, Forrester of MIT founded System Dynamics and applied its concept of information feedback system to business management, urban studies, ecology and other practical issues with great success. Oasis is a typical geographical entity of the arid environment and its ecological system strongly relies on water resource in the river system. The cohesive form and clear boundary of the oasis make it ideal for the application of system dynamics theory. 1 Oasis eco-economic system and its feedback structure 1.1 Oasis eco-economic system In arid regions due to insufficient natural precipitation the primary process of agricultural production--photosynthesis--is dependent on irrigation. Land use is heavily concentrated and is dominated by intensive agriculture. As the symbol of human civilization in arid regions, the structure and function of the oasis usually evolve from simplicity to complexity and from closeness to openness over time. Oasis system is a complexity of natural, cultural, and economic elements that mutually interact and reinforce in a specific spatial setting. It thus possesses many unique features that are not found in ordinary regional systems. First, in arid areas, oasis represents a man-made landscape with a high level of concentration clearly differentiated from the surrounding desert or gobi environment. The boundary of oasis is clearly marked. Second, natural resources such as water, soil and human and technological conditions inside the oasis make it the most productive part of the geographical system in an arid region. Of these water is the crucial element, the primary limiting factor in economic development. The scale of economy to a large extent depends on the scale of development of water, its management and utilization. Third, two distinctive tendencies of the oasis system can be identified, that is, from simple to complex, from closeness to openness. Since oasis is surrounded by the desert environment which limits its expansion, the oasis system often develops economic structures which are "small but comprehensive". At the early stage of evolution, resource and socio-economic development is increasingly concentrated inside the oasis. But as the economy advances the conservative nature of oasis system gives way to openness to larger areas as connection with the outside world increases. In other words, both spatial concentration and openness will increase, and the oasis system will become more complicated and advanced. Fourth, the oasis ecological system is fragile and susceptible to change, with limited environmental capacity. The oasis is often faced with many forms of natural hazards such as drought, sandstorm, marshes, salinity and dust-storm. With limited precipitation and excessive levels of evaporation, over dependence on irrigation, and influence of the surrounding desert, oasis is especially vulnerable to secondary salinization, bogging, and desertification. 1.2 Feedback structure of oasis economic ecological system The feedback structure of the oasis economic ecological system can represent several principal relationships in the following: First is the positive feedback between industrial and agricultural productivity. The typical oasis economy is based on primary agriculture and on the processing of agricultural products. Agriculture provides raw materials for industries in the economy. But industries in the oasis also provide products needed in agriculture, products such as energy, machinery, fertilizer, and pesticide which can positively affect agricultural production. Second is the positive feedback between agricultural, industrial production and social productivity. The positive relationship between agricultural and industrial production will in turn stimulate development of other industries, thus expanding the overall social productivity and productive accumulation which will in turn affect industrial and agricultural development through investment conversion. This is also a positive feedback. Third comes the positive feedback formed by water resource development. The scale of water resource development to a certain extent determines the scale of economy in the oasis. Higher levels of development and utilization of water resource can bring about economic development while economic development can provide capital for further development of water, forming a positive feedback. Fourth is the positive feedback of increase in overall social consumption. Increase in consumption follows increase in overall income. Increase in consumption will stimulate the economy and result in further increase in income in two ways. First, increase in overall social consumption will strengthen the scientific management ability of society, increase investment in cultural activities and education, and make the social economic system more scientific, orderly, and efficient. Second, increase in per capita income will increase people´s living standards and the quality of the labor force which will in turn impact social productivity and increase overall income. Fifth is the negative feedback between productivity and water resource utilization. Both industrial and agricultural production in the oasis demand large quantities of water. As industrial and agricultural productivity increase, water reserves will decrease and constrain further growth in economic productivity. This is the most vital negative feedback in the oasis system. Sixth is the negative feedback between productivity and environment. Industrial and agricultural production will cause environmental degradation. The ecological system in arid areas has very limited purification capacity and is vulnerable to environmental problems. Improper use of natural resources and lack of environmental protection can easily cause environmental degradation and will ultimately affect industrial and agricultural production. In all, although the feedback structure of the economic ecological system of the oasis is similar to those in other regional systems, there are significant differences. First, well-marked boundary means that the oasis system is more conservative. Second, the negative feedback between industrial and agricultural production and water occupies a prominent position. Third, ecological environment in the oasis system is more fragile. 2 An oasis dynamics model: taking Manas oasis as an example The Manas oasis is located on the northern side of the Yilianhabierduo Mountain of the Tianshan Mountain range. Administratively it belongs to the Manas and Shawan counties and the city of Shihezi. It is 8,662 km2 in area of which 2.8×105 hm is under cultivation. Manas is the largest oasis on the north side of the Tianshan Range and its economy combines agricultural and industrial activities. The Manas oasis presents a good example for the application of dynamics model. 2.1 Dynamics mechanism of economic growth in Manas Economic growth can be regarded as a function of the changing oasis economic ecological system and it is determined by many environmental and human factors which are interrelated through the feedback networks of the system. In order to understand the future of economic growth, it is necessary to determine both the quality and quantity of the relationships between these factors, especially in how they are related to the productivity of the economy (Han and Chen, 1994). The oasis economic system is presented below based on the current economic and data collection system of China. First, the overall socio-economic production is made up of agricultural, industrial and other economic activities including infrastructural construction, postal services, transportation and commerce. Their total productivity makes up total social output. Second, from a practical point of view, total social output is made up of complementary capital and net social output (or gross national income). The former is payment for material consumption in the production process while the latter is payment for factors of production such as labor, capital, and land. Third, national income ends up in two ways, i.e., consumption and accumulation. The former is divided into citizen consumption and group consumption while the latter can be divided into productive accumulation and nonproductive accumulation. Fourth, citizen consumption is necessary for maintaining the labor force, although from a human point of view it is the goal of economic production. Group consumption can be seen similarly, but it also maintains the organization and management of the social and economic system, keeping it in order and efficient. Fifth, accumulation for production is used for the expansion of production. Non-productive accumulation usually ends up in consumption. Sixth, part of citizen and group consumption will end up in "social accumulation" and as a result some social products will be left outside the economic system. But the financial sector can bring these products back into the system. Financial investment, accumulative investment in production and outside investment make up the source of capital needed for expanding production. Seventh, the scale of oasis economic system is to a great extent determined by water resource, land resource, and good environment which are closely related to industrial and agricultural production in the oasis. Eighth, different units of production are directly or indirectly related to one another. Equilibrium between these units is maintained through adaptation to changes in the environment. 2.2 Overall structure of the model and characteristics of the main sub-models This model aims to address seven factors in the system: 1) formation and distribution of gross social output and national income; 2) origin and distribution of investment capital; 3) population and labor force; 4) water resources development, their utilization and distribution; 5) industrial economy; 6) agricultural economy; and 7) regional carrying capacity for population. The sub-model for the origin and distribution of investment capital is presented as: where IVt is the amount of investment capital in the region within t; AIt is accumulation for production allocated from national income within t; AOt stands for accumulated production capital invested during t; β stands for ratio of consumption in national income; NIt stands for national income during t; γ stands for marginal consumption trend of citizen consumption; and INt stands for outside investment during t. A dynamics model for population and labor force is analyzed using the "state variable method" in which 808 variables are determined by residential status (rural or urban), ethnicity, gender, and age of population. The equation is shown below: Equation (2) is used to track the variables of those between age 1 and 100 (those aged above 100 is put under 100 group); equation (3) is used to track age 0 (under age 1). In equation (2) Pi, m, k, j stands for the number of people belonging to the four categories of i, m, k, j (representing residential status, ethnicity, gender and age); SP stands for the number of people in these categories in the earlier period; RD stands for mortality of the population; PM stands for net in-migration. In equation (3), K2 in Pi,m,k2,j stands for female and PI,m,k2,j stands for the number of female population with I, m, j. Fi, m, j stands for distribution of women within the ages of fertility and with I, m; W1, W2 stand for the upper and lower age limit of fertility; K stands for sex ratio of the newly born; β is policy variable of family planning, defined as the number of children allowed to a couple by the government. In the sub-model of industrial economy, the industrial enterprises in the Manas oasis are divided into 15 categories, which are then put into two groups based on their level of dependency on agricultural products. The first group includes industries such as textile, food, leather, and sugar whose growth is highly dependent upon agriculture. The growth of the second group is determined by the scope and overall structure of the economy; it includes the energy industry, machinery, electricity, and metallurgy etc. When considering the importance of such factors, the model uses economic data of the Shihezi district. In developing the sub-model for agriculture, we divided Manas oasis into ten agricultural districts of water utilization according to geomorphology, climate, water resource, structure of crops and level of socioeconomic development. The agricultural sub-system is divided according to the traditional method into five groups, including cultivation, animal husbandry, forestry, village industries and fishing. There are two environmental problems in the Manas oasis, namely, degradation of agricultural resources and pollution of urban environment caused by high densities of industrial development and population. Degradation of agricultural resources has deep implications for the oasis and the mechanisms are complex. Both natural factors such as geomorphology, hydrology, geology, climate and human factors are involved. Degradation of agricultural resources is also very spatially oriented and take the form of sandy soil, desertification, sandstorms, salinization, expanding marshes, decline in soil fertility, and deterioration of vegetation. Among these the most active and serious are desertification and salinization. Desertification is most serious around the Gurbantunggut Desert, in Regiments 121, 148, 150 of the 8th Agricultural Division of the Army. The Gurbantunggut Desert mainly consists of semi-stable sand dunes. Except for areas where natural vegetation is in good condition, tree belts need to be built and maintained to protect farmland and stabilize the desert. The model uses an index for tree zones of farmland protection and the area of tree zones of desert stabilization. If these fall short of requirements because of financial or water shortage, a decrease in the scale of agriculture is recommended, namely, some farmland should stop cultivation. The main difference between salinization and desertification is that the former occurs typically in shallow areas where drainage is poor while the latter takes place near the front of sandstorms. In this model, lightly and moderately s alinized land is regarded as land with low productivity which can be turned into highly productive land with investment and reclamation. As for urban pollution, the model mainly considers the pollution of water resource in and around urban areas. It uses the amount pollutants in water as horizontal variable and the difference between amount of pollutants and the maximum amount of pollutants allowed as environmental capacity. Since the amount of pollutants and the degree of harmfulness vary greatly from industry to industry and depend on the type of technology used and there are wide differences in the physical and chemical contents and in harmfulness, a "pollution" index is used in the model which enables comparison in the harmfulness between different pollutants. Public sewage is calculated on the basis of population and this, together with industrial sewage, constitutes the main inflow of urban water pollution. The outflow of urban water pollution depends on two factors, one is the capacity for water resource to purify itself and the other is sewage treatment. The latter requires investment and is related directly to technological development. 2.3 Model testing Simulation models need to be tested before application. Two items are usually included in testing: 1) relationship between the structure and behavior of the model, and 2) compatibility of the structure and behavior of the model to real systems. Testing for the two items should not deviate from the purpose of model building, i.e. it should focus on the main problems and should be helpful in evaluating the truthfulness and efficiency of the simulation results. To test the truthfulness and efficiency of the model, it is important to compare simulated values of key system variables to realistic data, to see if simulated results match the historical data in the real world. We choose three system variables, i.e. national income, total industrial output, and total agricultural output and compared the statistical data to simulated results. Both are shown in Figure 1. Figure 1 shows that simulated results closely match historical data. Average differences of error for total industrial output and national income are below 5% and difference of error for total agricultural output exceeds 10% in only a few years. Greater errors in agricultural output are understandable; they can be attributed to unpredictable changes in climate and water supply which have an undue impact on agriculture. Moreover, influenced by the market, area of cotton cultivation in Xinjiang has increased at above normal speed in recent years; this is contrary to the model´s presumption for an optimum structure of agricultural cultivation. Laying aside areas of significant errors of difference, we can conclude that the simulation model accurately portrayed the mechanisms of economic development in the oasis setting and predicted its trend of development. This study also demonstrates the usefulness of system dynamics theory in studying complex random systems. 3 Model application: evolution of Manas oasis ecological economic system and relationship to key policy variables 3.1 Trend of economic development 3.1.1 Gross social output and income Changes in total industrial output, total agricultural output, and total social output in Manas from 2000 to 2010 are shown in Figure 2, according to the results of model simulation. In this figure, economy in the next 10 years assumes a pattern of steady and rapid growth, in which total industrial output will increase at 6.70%, total social output and income at 5.49% or higher while agricultural growth appears slower with an average rate of about 2.05%. This is because the agricultural resource base--especially water--has been used almost to the maximum and agricultural growth is highly restrained. 3.1.2 Industrial structure According to the results of model simulation, with rapid growth in industrial production, transportation, postal services and commerce in the next 10 years, the proportion of manufacturing industries in total social output will increase. The proportion of industries in the total economy will increase from 41% in 2000 to 48.7% in 2010. The proportion of transportation, post and commerce will increase from 5.18% and 11.1% in 2000 to 6.14% and 12.7% in 2010. But the proportion of agriculture will drop from 39.5% in 2000 to 29.7% in 2010. Within the manufacturing sector, the proportion of textile and food processing will decrease while those of machinery, metallurgy, chemical industry and clothing will increase. Within agriculture, the proportion of animal husbandry and village industries will increase while those of food cultivation and forestry will decrease. 3.1.3 Regional investment capacity According to the simulation model, the investment capacity of the Manas oasis in the next ten years will increase by 1.61 times, with an annual increase rate of 4.86%. Among the sources of investment capital, productive accumulation investment will come directly from income and will therefore bear a strong correlation to income. Financial investment mainly comes from social accumulation and will increase by 1.57 times, with an average annual rate of 4.64 %. 3.1.4 Citizen consumption According to the simulation model, per capita income and consumption will increase by 1.7 times or higher in the next 10 years, with an annual increase rate of 5.49%. 3.2 Impact of cultivation on overall oasis economy The agricultural sector of the economy, the structure of cultivation in particular, will have direct impact on the overall oasis economy. We tested the impact of three types of agricultural activities on the economy using area of food production in total area of cultivation, namely food production type (over 40%), mixed cultivation type (around 30%), and cash crop cultivation (less than 25%). The result shows that the last two types of cultivation will have more direct impact on income increase in the oasis economy and will therefore be more beneficial to the oasis economy, confirming the high level of dependenc e of oasis industries on cash crops. 3.3 Impact of accumulation rates Accumulation rate is an important policy variable in the oasis socio-economic system and has direct impact on the relationship between social consumption and investment. We therefore selected three accumulation rates, 0.2, 0.25, and 0.3, as parameters for simulation. The result shows that higher accumulation rates are slightly more beneficial for increasing total social output and income, but this impact diminishes over time. On the other hand, higher accumulation rates have greater impact on per capita consumption (with a 13% difference between the highest and lowest) and it increases over time. According to the simulation model, the best accumulation rate is between 0.2 and 0.25. 3.4 Regional investment policy simulation test 3.4.1 Investment ratio between industries and agriculture The interactive and feedback relationships within the economic ecological system are complicated and it would be hard to determine the best rate of investment between industries and agriculture using traditional methods. Using model simulation method we tested the economic effects of three scenarios of investment ratio between industries and agriculture, namely 1:3, 3:5, 1:1, and 5:3. Using national income as criterion, the results are shown in Figure 3. From Figure 2 it can be seen that higher industrial investment in scenario four (5:3) will result in high economic growth in the near term but long-term economic effect is not as good as in scenario one (1:3). On the other hand, higher agricultural investment in scenario one (1:3) will lead to stable growth in the long term but economic growth in the near term will remain at a low level. Therefore the best scenarios seem to be in between, namely scenario two (3:5) or three (1:1). 3.4.2 Optimum rate of investment in water resource development It is important to come up with the right level of investment in water resource development. Using model simulation, we tested the effects of three levels of water resource investment in terms of its proportion in total investment in production. We used the average annual increase rate of total industrial output, total agricultural output, and total social income as parameter. The results are shown in Table 1. It can be seen that the best investment rate for water resource is 7.5%. Inappropriate investment will either lead to insufficient water resource and therefore limit economic growth or to inefficient use of capital. 3.5 Environmental management strategy In the model, optimization of the oasis environment is accomplished gradually through management strategies, including: 3.5.1 Planning and spatial coordination To preserve the oasis environment of the oasis it is important to look at it from a system point of view. Special attention needs to be given to the relationship between the mountain environment and the valley environment of the oasis, between oasis and the surrounding desert, and between the upper and lower reaches. There needs to be comprehensive planning about economic development and environmental improvement. Water resource should be developed on a reasonable basis and environmental issues should be given primary consideration. Water resource must be distributed carefully, and balance must be maintained between water and soil and water and salinity. Agriculture must be directed by environmental principles. According to long term planning goals for the Manas oasis, the northern part of the Manas oasis need to be provided with tree zones both to protect the farmland and to stabilize desert advance. The ratio between farming, forestry, and animal husbandry in irrigated areas should be 6:3:1. Forest coverage should reach 15-20%. The middle and upper reaches of the oasis should mainly develop agriculture, sugar, cotton, animal husbandry, protective tree zones and water pollution control projects. It should be completely covered by tree zones and the ratio between farming, forestry, and animal husbandry should average 7:2:1 and forest and tree coverage should be 10-20%. 3.5.2 Prevention of soil salinization In light of the causes of soil salinization in the Manas oasis and its growing trend, two measures should be adopted to prevent it. First, hydrological projects can be built to control and balance water and salinity in irrigated areas. Secondly, farming and biological techniques can be used to improve oasis environment and put it on a healthy sustainable base. Emphasis should be on prevention and agricultural, biological, and hydrological projects should be applied in a balanced way. 3.5.3 Balance between utilization and conservation, sustainable development, increase in soil fertility Balance between utilization and conservation consists of rotation of crops between farm crops and grass and green fertilizer and the returning of crop remains to soil. Sustainable development means developing eco-agriculture, comprehensive management of forestry, water, grass and soil, creation of scientific cultivation system, building of protective trees zone, and the development of animal husbandry near farms. Forestry and grassland should be combined. Organic fertilizers should be applied on a large scale while chemical fertilizers should be limited. Protective tree zones should be increased and maintained. Biological salinity reduction tree zones should be planted along irrigation networks. Tree zones should be planted on the edge of deserts to stop the advance of sand and tree cutting should be strictly prohibited. Trees, shrubs, and grass should be combined to form a vertical structure of protection. Zones of large trees should be planted around deserts for protection against winds and for the stabilization of sand, and grass zones should be planted next to them. 3.5.4 Elimination of pollution sources and control of pollution expansion Industries are the chief source of pollution. Thus the following measures may be adopted. First, quantity of pollutants can reduce through improvements in technology. Secondly, sewage and poll

ution treatment plants can be built when economic development reaches a certain level. 4 Conclusion System dynamics method starts from studying feedback structure within the system under study and searches for the best solution through finding the right "policy point" and by model simulation in the computer. It embodies the cream of "systems cybernetics theory" and is scientific. The above analysis of the oasis system in the arid region is justified because of the nature of the oasis system and the simulation results are scientifically sound and practically feasible. References

关键词： oasis; dynamic modeling; Manas oasis

