DYNAMIC MODELLING AND POLICY ANALYSIS ON TECHNOLOGICAL PROGRESS AND THE CHANGE OF INDUSTRIAL STRUCTURE

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ABSTRACT

Based on the mechanism of interaction among R&D, technological progress, the change of industrial structure, and economic growth in both supply and demand sides, and with the help of dynamic input-output analysis, in this paper a system dynamics model is constructed, focusing on the notable impacts of technological change on structural change in the Chinese economy. Through modelling and policy analysis,some new findings and patterns of long-term development, including the preferential consequences and opportunity for industrial development, future prospects for China's S&T and economy during the next fifty years, the evolution of industrial structure in the process of industrialization, and resource allocation to different industries and R&D expenditure allocation, are obtained.

I. INTRODUCTION

Compared with Hollis B. Chenery's "standard structure" or "general large country structure", and based on international comparisions of industrial structure, China, though a typical low-income large country, is characterized by an upper-middle-income country with 1000 or more U.S. dollor GNP per capita in terms of the share of industry in production structure (about 42.6% of GDP in the year 1981). On the other hand, looking at the share of the labor force in agriculture (69.6% in 1982), it has the characteristics of a typical low-income country. The contradiction and abnormal devirations are related to defects in China's industrialization development strategy. During the past decades, China's economic growth had been fueled mainly by the growth requirement of self-ordering heavy industry, and caused the inbalanced or irrational patterns of industrial structure.Less-developed agriculture and basic industry acted as a bottleneck have restrained the growth of the entire economy, and equipment-manufaturing industry expanded so quickly that the raw material industry & energy industry and infrastructure could not satisfy its overdevelopment. At the same time, the consumption goods industry had been neglected and were usually in serious short supply. It is estimated that the idle production capacity of the machinebuilding industry is as high as 20% to 30% because of the barriers of the unbalanced structure.

Meanwhile, China's industrialization had been pushed forward thoroughly in urban areas. Moreover, most of the country's population (about 70-80%) was in rural areas producing small portion of national income, so that the rural population was isolated from the industrialization process. Many development economists believed that in developing countries the economic development process is a shift of surplus labor from traditional sectors (agriculture with zero or even negetive marginal productivity of labor owing to its unlimited supplies of labor) to modern sectors (manufacturing,etc.) according to the dualism theory. It is inadequate simply to depend on the expansion of modern sectors to absorb agricultural labor. Moreover, the expansion of rural nonagricultural sectors should be included and accelerated. Hence , rural or rural population industrialization become a part of the entire industrialization. In this way, the deviration or defect occured during the past course of China's industrialization.

The lower income per capita is derived from an unbalanced or disequilibrium and lower-level of industrial structure other than lower productivity or lower industrial technical level.In brief, the crux lies in the lack of coordination or cooperation between the output structure and demand structure. Furthermore, the profound reasons hidden behind the unbalanced or disequilibrium structure are that the transfering capacity of the production structure hindered by an industrial technology system can not be content with the sharp change of consumption structure.

Hollis B. Chenery and M. Syrquin concluded, in their "Pattern of Development 1950-1970", that Engel's coefficient (the income elasticity of demand for food) demonstrates a significant downward trend as per capita income rises over time especially within the areas of 100-1000 U.S. dollar GNP per capita, in other words, the weight of consumption of food falls rapidlly. Therefore, low-income countries will enter the stage of the greater change of industrial structure. Large countries, however, will do so even at a lower-income level (per capita GNP estimated at 270 U.S. dollars or so). Thus, in China (300-400 U.S. dollars) what is happening is something towards the new development stage characterized by the great change of industrial structure. In addision, Petty-Clark's law and Simon Kuznets' study revealed that a country's economic development is closely associated with the change of industrial structure, hence growth process is just one of structural change.

The change of industrial structure may be viewed as the results of overall interactions of such multi-factors as technology, natural resources,economy and society. In short, the prevailing factors would be summarized as both supply and demand factors. The structural change will appear only when one or all of these factors begins to change. Furthemore, technical factors have a direct effect on both supply and demand factors, and then further on the structural change. Consequantly, the structure of the technological system sustains or restrains the change of industrial structure. Interindustry linkages, in fact, are the interration and interdependence among industrial technology. As a result, technical advance is the governing factor affecting the structural change.

Therefore, in this paper, the train of thought is developed from Research & Development (R&D) and innovation to technological progress to the change of industrial structure and finally to economic growth, throughout which both supply and demand sides are taken into account respectively.

In analyzing sources or factors of economic growth, both Edward F. Denison's and Hollis B. Chenery's work is well-known. Denison's work attempted to enlarge as many kinds of input factors as possible and to estimate the contribution of various input factors, and output per unit of input, to growth. Obvisously, Denison, in measuring the contribution of technical advance to growth, adopted, on the whole, a

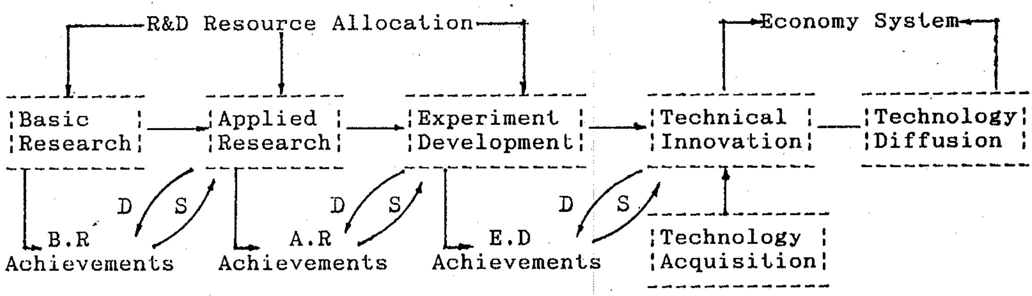
" black box" methed. This, as Denison noted, is the measurement of our ignorance. On the contrary, Chenery's work applies input-output analysis to measuring the impacts of demand factors (consumption, investment, import & export, technical change, etc.) on structural change and on growth. Furthemore, increases or decreases in input requirements, represented by changes in input and inverse coefficients, are interpreted as technological change.

Generally, both works are based on supply and demand side repectively. Hence, this analysis of single side is definitely limited and incomplete in portraying the picture of structural change in the future, as structural change and growth are regarded as overall effects of the combination of both sides. Therefore, in this paper both side factors will be taken into comprehensive consideration by means of System Dynamics.

II. MODEL DESCRIPTION AND MECHANISM

S&T and its Application in Economy System

As the staple of S&T activities, R&D is also regarded as the input-output process in which inputs of various resources bring about R&D achievement outputs (see Fig.1). Only through its application to the production process do R&D achievements become practical production capacity which will lead to technical progress, otherwise, potential productivity. Consequantly, technical advance is mainly derived from the application of achievements, in both self-developed R&D and technology acquisition, to economic system.



Note: S--Supply support, D--Demand

Fig.1 R&D Input-Output Process and its Application

Factors influencing the application of achievements, that is, the jump of potential towards realistic technology, are shown as follows:

(1) Demand for Achievements

System and Environment They determine the interest of enterprice in technical innovation and the demand for achievements, strong or weak. In particular, the extent of the perfection of market competition and the integration of S&T with production make a direct or undirect effect on the demand intensity.

- Investment From the point of view of Soviet Union scholars, the application of achievements is achieved only through capital investment in which up-to-date technology is usually embodied. Thus amount of capital investment, particularly, that in technological transformation will determine the potential demand of the economic system for achievements.

- The absorptive capacity for technology. The causal relationship between industrial technological level and the absorptive capacity for achievements indicates that the lower technological level is an obstacle to the enhancement of the absorptive capacity, and vice-versa. The weak absorptive capacity hinders increase of technical level. In this way a vicious circle is maintained which prevents economic growth. The successful experiences of some developing countries show that it is effective to break away from this predicament by improving the quality of human capital through education and technical training. Especially while developing countries are faced with the insurmountable technical gap, technology acquision is neccessary for economic take-off.

(2) Supply Side of Achievements

- Qualities of Achievements: advanced and appropriate or not,and potential economic effectiveness, etc..

- Reserves of achievements. Through proper choices achievements may be applied to the economic system. Accordingly, the more reserves of achievements there are, the wider choice margins there are, and the higher the choice efficiency is.

As a result, Fig.2 presents the interaction mechanism of S&T and its application.

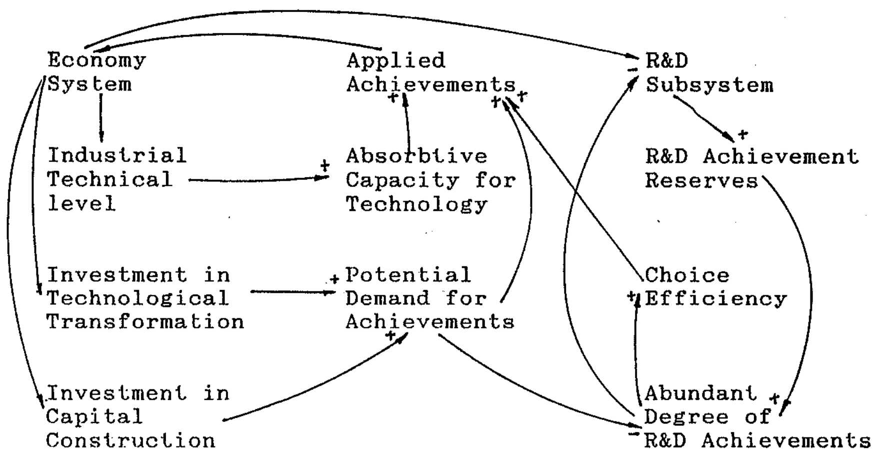


Fig.2 Application Process of R&D Achievements

Technological Progress, Structural Change, and Resource Allocation Mechanism

Technological progress has a directly notable impact on both demand

and supply factors, and then further on the structural change. In demand side, the structure factors include intermediate demand, final consumption, final investment demand, and export. Here the more detailed discussion is only on the intermediate demand structure. Based on the international comparisions of material use, China's consumption of raw material and energy is especially high. For example, its energy use is 5.69 times as large as Japan's and its steel material use is 2.8 times Japan and twice United States. In addition to China's special GDP structure, the lower intermediate use efficiency, which is brought about by the lower industrial technology level and backward management, are the major reasons for this imbalanced usage. According to interindustry analysis, changes in input coefficients can be caused by many factors, such as vertical concentration over time, often combined with a changing product mix and shifts in industrial product composition. Nevertheless, the prevailing factor is technical change, which will make the change in input coefficients tend downwards.

In supply side, dominant factors consist of supply structure and allocation structure of various resources other than industrial technology. There are two basic types of resource allocation mechanisms or economic operational mechanisms--goverment planning regulation and market regulation.Among government planning regulation,demand management is basically composed of fiscal and monetary policy, and supply management is mainly made up of industrial policies (industrial structure policy,industrial organization policy and industrial technology policy, etc.). Industrial policies can link up planning regulation with market regulation. Besides, government regulation mechanism should work in coordination with market mechanism as prevailing hand in order to move the structural change into a higher and more balanced level. In the meantime,government regulation should make up for the failure and functional weakness of market regulation. What's more, however, it ought to ensure coordinative development among S&T,economy and society, and finally carry out the national development strategy. To sum up, factors having an effect on structural change and growth are decribed in Fig.3, and the overall interaction machanism is given in Fig.4.

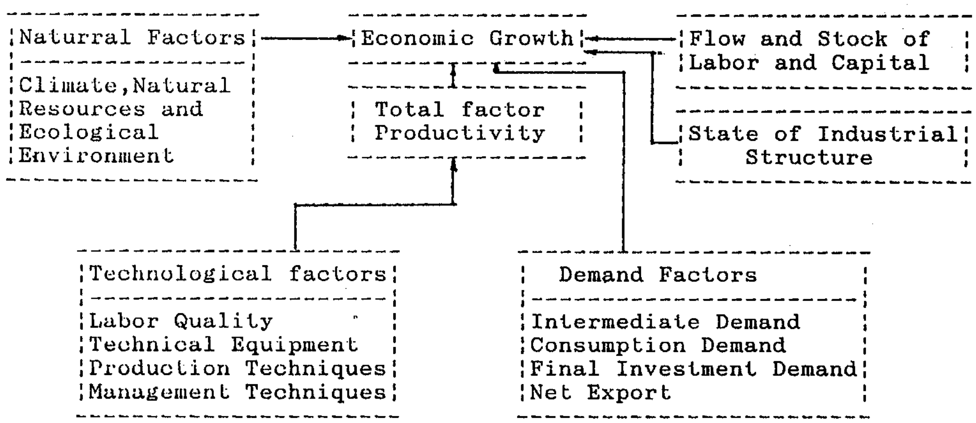


Fig.3 Dominant Factors Effecting Economic Growth

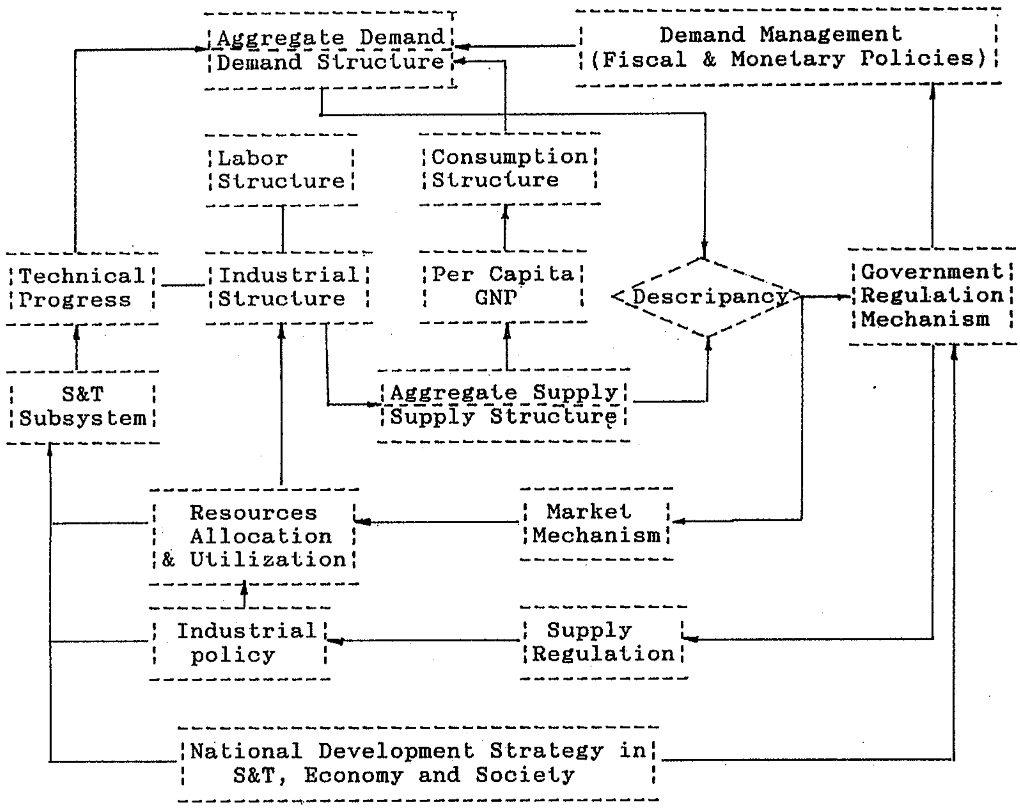


Fig.4 Interaction Mechanism of S&T and Economy System

Model Description

With the help of a dynamic input-output model and on the basis of the coordinative development between S&T and economy, a system dynamics model is constructed, focusing on the notable impacts of technical change on structural change. This SD model is composed of six subsystems, including S&T, agriculture (abbreviated as 'A'), final consumption goods industry ('FC'), intermediate goods industry (i.e. energy & raw material industry, abbreviated as 'I'), final investment goods industry (i.e. equipment-manufacturing industry, abbreviated as 'FI'), and construction industry & infrastructure ('CI'). The above-mentioned industry classification is consistent with MPS (i.e. The System of Balances of the National Economy), and is based on the Chenery-Watanabe four-way categorization of productive sectors for China (1981) and the analysis of interindustrial linkage effects. These effects are measured by both forward and backward linkage effect in terms of China's input-output tables available for 1981 and 1983. The interaction between the aggregate system structure and its environment is shown as follows (Fig.5).

As industrial subsystem is similar to each other, we will concentrate upon the description of the final investment goods industry. The more detailed causal-loop diagram of machinebuilding industry is based on the simplified one(Fig.6).

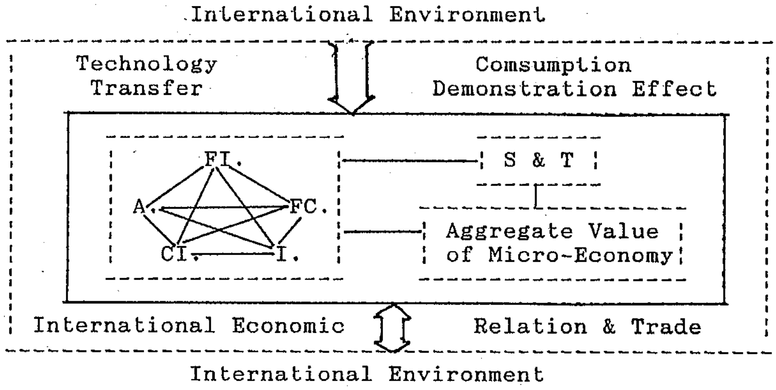


Fig.5 System Structure and Its Environment

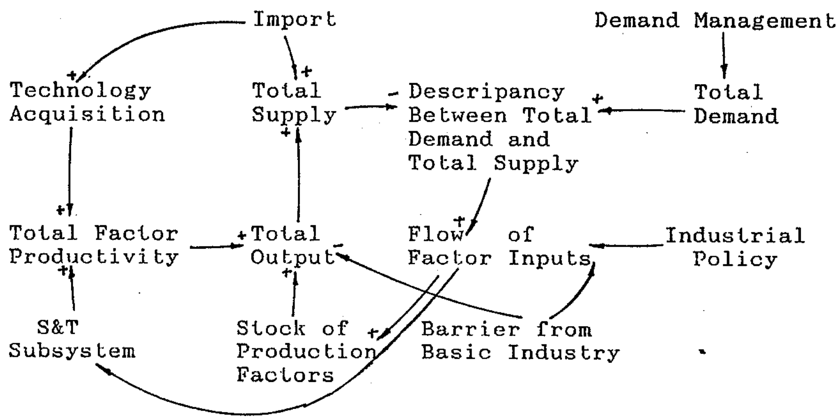


Fig.6 Simplified Causal-Loop Diagram of Final Investment Goods Industry

Five industrial subsystems are integrated with S&T subsystem and aggregate values of micro-economy.

III. POLICY TEST ANALYSIS

Basic Behaviours in Base Run

Under a set of policies and economic conditions, such as the coordinative development between S&T and economy, demand orientations, the middle accumulation rate at a level of 29% to 31%, and the proper or moderate demand expansion, the system behaviors in the fifty year span from 1985 to 2035 are simulated as follows:

- National Income (Fig.7). Annual growth rate of national income will fluctuate within a 4-7 percent range. However, during the late stage it will demonstrate a downward trend. Per capita income (yen at 1980 prices) will go from 533 in 1985 up to 1260 or so in 2000.

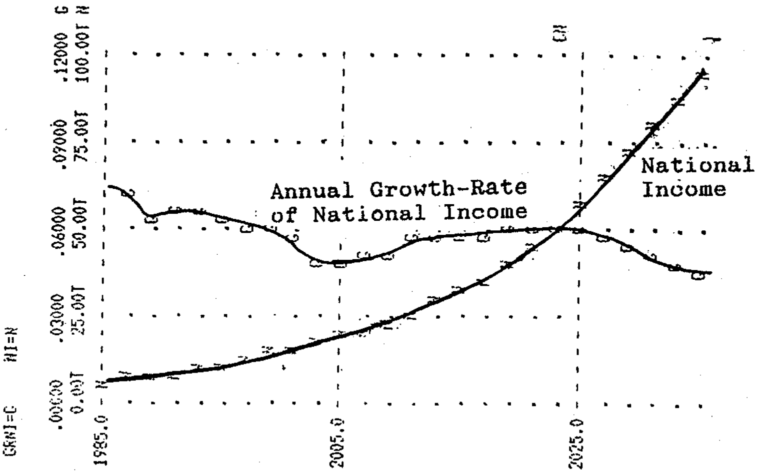


Fig.7 National Income and Its Growth-Rate, 1985-2035
(NI: Hundred Million Yen at 1980 Prices)

- Production Structure (Fig.8). The proportion of agriculture declines continuously and its gross output value constitutes about 12.8% of total products of society around the year 2035. Conversely, construction industry & infrastructure grows most rapidly since supported by a vigorous or excessive demand for it. Its index of gross output value grows in the same way. Contrary to audio-visual judgement, the share of investment goods industry will not go up, but will go down slightly, because insufficient demand for it restrains its expansion. After the year 2008, however, its share will begin to experience a upward trend due to the support of demand expansion.

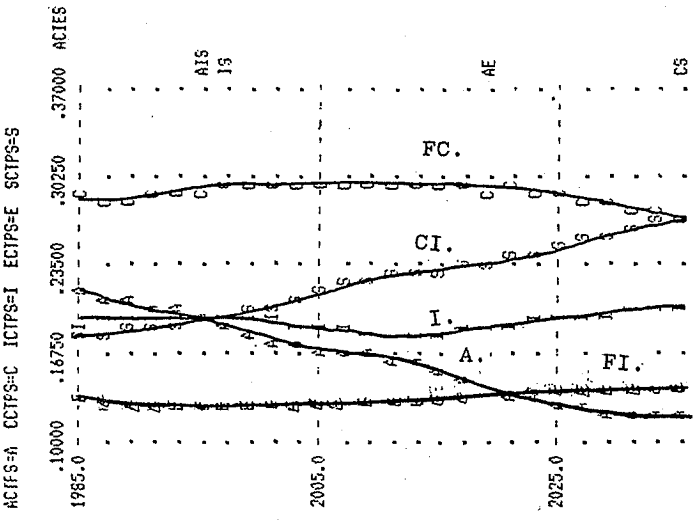


Fig.8 Production Structure
(Proportion to Total Products of Society)

- Sectoral Distribution of Employment. The two objectives pursued by a country's industrialization are the upgrading of industrial structure, estimated by the ratio of manufacturing value added to commodity value added, and preferrably more than 60%,secondly,the shift of agricultural labor to non-agricultural sectors. The simulation results show that the share of construction industry & infrastructure goes from 12% or so in 1985 up to 25% in 2035, and that of whole industry (FC. plus FI. plus I.) from 17% up to 33%. Thus, the shift of agricultural labor will primarily have been achieved roughly by the end of simulation.

- R&D Expenditure (Fig.9) During the period 1978-1985, China's R&D expenditure constituted about 1.5-1.8% of national income. The modelling results show that the R&D expenditure as a percentage of national income goes from 1.78% in 1985 up to 2.9% in 2008. Later it reaches its relatively stable value while the demand of the economic system for R&D achievements rises steadly and S&T is integalated with economy organically. On the other hand, growth rate of R&D expenditure , which exceeds that of national income during the initial few decades, remain at 8-9% owing to the barrier of limited resources. Then it stabilizes to 4.6-5.7% which is roughly consistent with that of national income. Generally, the share of R&D expenditure takes about twenty years to reach its stable value. However, the stable value is significantly affected by the application of achievements, or by the effective demand of industrial sectors for achievements. When the effective demand increases or decreases by 35% compared with the base run, the stable share approximates to 3.2% and to 2.7% respectively.

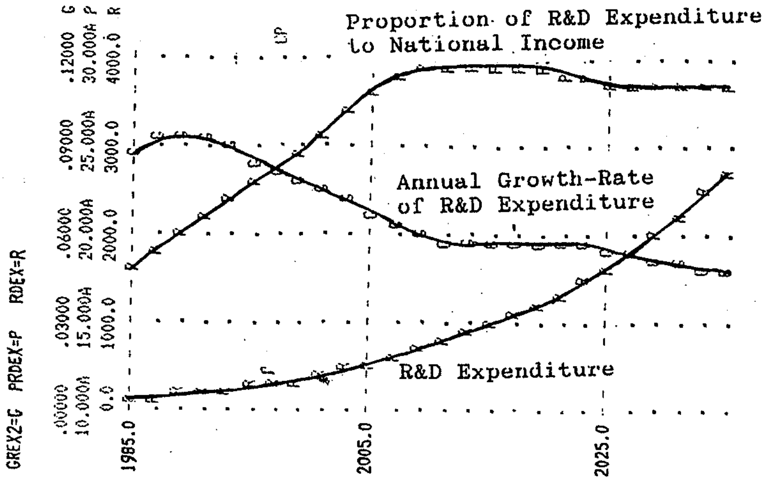


Fig.9 R&D Expenditure

Industrial Structure Policy: The choice of Leading Industry

Industrial policies include industrial structure policy, organization policy and technological policy. The essence of industrial structure policy as the core of industrial policy is to achieve economic growth and efficiency pushing industrial structure into the higher level. Design of industrial structure is primarily to provide the sequence and opportunity for industrial development. In addition, it is to

Considering forward and backward linkage effects (Tab.1), machinebuilding industry whose linkage effects are sufficient, can push and pull the development of other industries. For this reason, some scholars regard this industry as leading industry. However, works supporting this viewpoint lack quantitative analysis for long-term projections, which is the key to planning industrial structure. The base run indicates that during the first few decades,however, insufficient demand resuls in the serious idleness of its productive capacity, so that the share in production structure will fall slightly. As a result, the demand, as the major barrier, cannot support its development as leading industry when basic policies are implemented during the first few decades.

Under the new adjusted policies, such as the increase in each industry's depreciation, adding ratio of investment in technological transformation, and warm incentive to investment demand, new major behaviours are as follows:

- Machinebuilding industry will enter such a state of operation that demand for it will be greater than its supply after 1995 (see Fig.10).

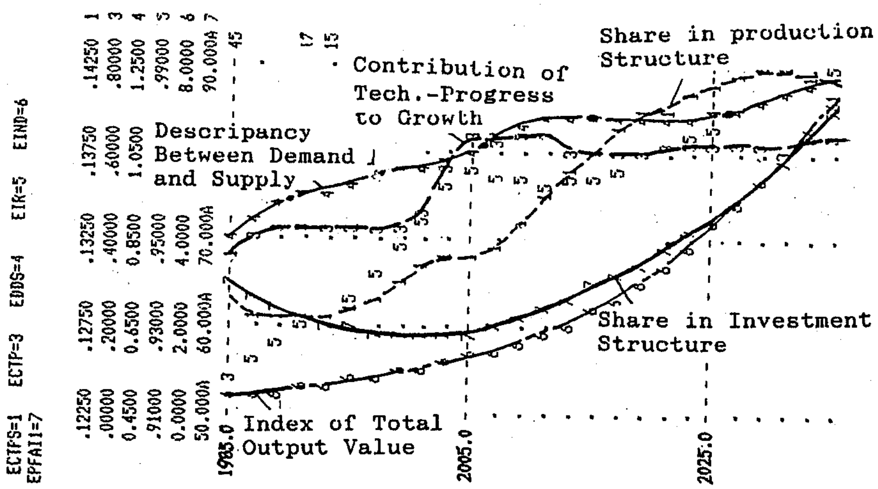


Fig.10 Behaviors of Final Investment Goods Industry

- Final investment goods industry will have expanded its share in production structure progressively, and the index of gross value of its output becomes second to that of construction & infrastructure.

- Compared with the basic behaviors, national income will go up by 5.1% in 2035,R&D expenditure will grow to constitute 3.05% of national income around 2030 compared with 2.86% in the base run.

Based on the foregoing results, the preferential consequences and patterns of industrial development can be achieved. At first, contributors to bottleneck of industrial structure, such as transportation, power and raw material, should be given priority in policy-making and resource allocation. Then, capital inputs and innovations in agriculture should be enhanced in order to achieve continuous steady growth. Even if some industries have certain characteristics of choose leading industry (or strategical industry) which can develop industrial structure into a more balanced or rational and high level by the mutual effect when combined with implementing of other technological and economic policies to subsidize leading industry.

The choice of leading industry is dependant upon a country's reality and which stage of economic development a country is in, along with certain criteria. Both 'the criterion of income elasticity of demand' and 'the criterion of growth-rate of productivity', which describe the prerequisite of leading industry from the demand and supply side respectively, are the keystone of Japan's industrial structure policy. Through adopting the two critera in the 60's, the Japanese government chose 'heavy and chemical industries' as leading industry. Japan's choice was based on such situations as the shortage of natural resources, so that international trade was placed in the prevailing position. In China, however, in view of it being such a large country with significant inward orientation, interindustry linkage can scarcely be accomplished by international division of labor like Japan. Consequently, interindustry linkage, in particular, the driving effects of leading industry on the development of other industries, should be given more weight. That is, the third criterion--'linkage effect criterion'-should be take into account. The third criterion is measured quantitatively by two indicators: dynamic forward linkage effect and backward linkage effect. The former reflects the impacts or restraint of one industry on others through the supply of intermediate goods as well as final capital goods. The latter describes the extent to which one industry relies upon intermediate inputs of other industrial sectors.

In terms of the three criteria and modelling results in the base run, either final consumption goods industry, intermediate goods industry, or construction industry & infrastructure is partly characterized by the leading industry and the criteria. However, technological level and growth rate of final investment goods industry determine that of other industries, and furthemore, that of the entire national economy. Besides, intermediate consumption of raw material and energy is dependent on the level of technology and new development of R&D, which, to a great extent,is embodied in capital equipment.

Tab.1 Linkage Effects of China's Industrial Sectors in 1983

Sector	Dynamic Forward Linkage Effect	Backward linkage Effect
Agriculture	.43	.17
Metallurgical	.73	.33
Power	.84	.37
Coal	.80	.36
Oil	.70	.25
Chemical	.63	.39
Machinebuilding	.58	.43
Building Materials	.81	.45
Forestry	.58	.34
Food	.19	.62
Textile	.19	.27
Paper	.42	.40
Construction	.93	.74
Transportation	.79	.27
Trade	.41	.46

leading industry during the next few decades, leading industry will not have emerged. Hence, by the end of this centry, industrial structure should be pushed towards an equilibrium or rational level in order to estabilish the best starting point for the next centry's growth. Later on, with the rise of depreciation rate and ratio of investment in technological transformation, equipment-manufacturing, which will grow rapidly, will drive the growth and industrial technology level forward. Thus, during the later stage, the pattern is one of inclined development of final investment goods industry as leading industry on the basis of the coordinative development.

Analysis on the Evolution of Industrial Structure[*]

Considering the indicator--'heavy industry ratio'--formulated in terms of the modelling results under the adjusted policies, we conclude that, during the initial modelling periods, China will go through a course of continuous decrease of 'heavy industry-ratio'. This is different from developed countries whose portion of heavy industry rose continuously during its industrialization process. Why is this so? It is due to China's previous unreasonable pattern of over-expansion of heavy industry which will still have a great impact until the next few decades. Later, however,'heavy industry-ratio' will begin to go up and reach 55.9% around the year 2035. In this case, China will still be in the development stage centred upon heavy industry, compared with 'heavy industry-ratio' of various industrial countries in 1970--57.4%, 61.0% and 62.4% for U.S, Britain and F.R.G. respectively.

Tab.2 Heavy Industry-Ratio and Hoffmann Coefficient

Year	1985	1995	2005	2015	2025	2035
Heavy Industry Ratio	.525	.525	.517	.524	.541	.559
Hoffmann Coefficient	2.207	2.26	2.255	2.115	1.995	1.899

Studies by Japan's economists indicate, that, among those countries whose per capita income exceeds 200-300 U.S. dollors (calulated in 1950 prices), Hoffmann coefficients of countris with high industrialization level, or post-industry countries, more or less remain constant. Otherwise, Hoffmann coefficients of industrilizing countries will go down, and then reach its relatively steady level in a certain period. Contrary to this general rule, however, China's Hoffmann coefficient will have demonstrated a slightly upward tendency by the end of this centry. It will then fall steadly, at last, follow a gradual decline. Therefore, China will still have been in the middle and late stage of her industrialization during the next fifty years. From these analysis, we can conclude, that, the issues: which development stage China will be in and how to choose and plan the preferent consequences and opportunity for industry development, are provided with the basic knowledge and outlook.

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[*]: Here and later on we concentrate the discussion upon structural change among I., FI. and FC.

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