DYNAMIC MODELING AND POLICY ANALYSIS FOR NATIONAL R&D RESOURCE ALLOCATION DECISIONS

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ABSTRACT

The confliction between the need of R&D expenditure and the limitation of R&D resources in certain time period is a serious issue facing both developing and developed countries. This paper deals with not only the mechanism of interaction between R&D, economy and education systems, also the mechanism and relation among basic research, applied research and development. Two system dynamics models were developed focusing on the above two problems respectively. And, through modeling and policy analysis, some new findings, such as the proper scale and growth-rate of national R&D expenditure, the relation between technology acquisition and self-developing R&D, the proper ratio of R&D expenditure, etc., were accomplished.

I. INTRODUCTION

Science and technology(S&T) plays a more and more important role for current economic growth. As the staple of S&T activities, R&D has been continuously extending its scale. But, the resource is limited at certain time period, thus how to determine a proper amount of R&D investment, the ratio of resource allocation(structrue) between basic research, applied research and development, how to find the relationship & mechanism among them and how to develop the S&T and economy, effectiveness & efficiency of the allocated resource of R&D are serious issues facing both developing and developed nations since 60's.

Up to now, researches in these aspects were concentrated and limited in the following areas:

- The contribution of R&D to economic growth. Many papers focused on discussing how to determine as well as recognize the percentage of the contribution, such as Cobb-Douglas production function and so on. Although these papers discussed some problems about R&D resource allocation decisions, few dealed with such problems as how R&D affecting economy and how economy influencing R&D resource allocation decisions.

- The allocation ratio among B.R., A.R. and D. is few studied. There is a lack of necessary information and appropriate analysis methods, existing studies limited to some brief conclusions based on some statistical materials.

- Some basic mechanism and theoratical studies such as the process of R&D, the process of economic growth, the classification of R&D, the measurement of R&D achievements(*), interaction mechanism between B.R. and A.R., as well as A.R. and D., the input-output relation in certain kind of R&D, and so on. All these are fundalmental to the study of R&D resource allocation problems. Unfortunately, they are not systematical and rich enough for our research and some breakthrough are needed.

This paper attempts to recognize R&D resource allocation decision-making system. Two system dynamics models are built up to simulate the system and by testing the models, various R&D resource allocation policies are analyzed. It is particularly focused on:

- The results of different R&D resource allocation policies in a certain social-economic circumstance.

- How to allocate properly the limited R&D expenditure among B.R., A.R. and D. in different social-economic environment.

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* Here we take the achievement of basic research, applied research and development to be principally literatures, patents and new products & new processes respectively.

Two system dynamics models dealed with above two problems respectively.

II. FIRST MODEL----ALLOCATION SIZE MODEL(SDRDA)

Modern S&T has been a wide-ranging problem , which is reflected directely by the interaction among R&D system and social-economic systems. Two main factors--national economic development and R&D states--influence the size of R&D resource allocation. The former one reflects national economic potential as well as the needs to R&D; the later, mainly the capability of investment and manpower, embodies the ability by which R&D can contribute to economy. The basic relations connected to R&D resource allocation decisions among economy, education and R&D systems are shown as follows(Fig.1).

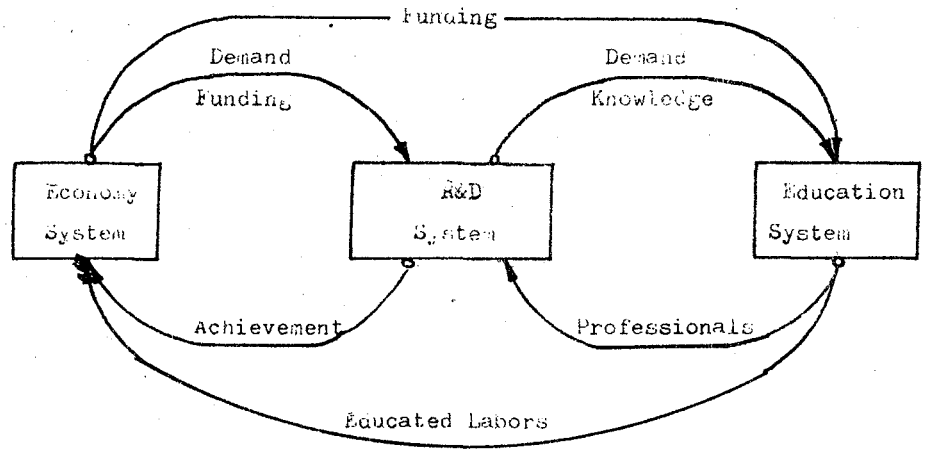

Fig.1 Economy--R&D--Education Systems.

Basic Economic Growth Process

Essentially, the process of economic growth is a process in which demand and supply contradict and balance. From this point of view, we could recognize the process as Fig.2.

As soon as the existing economic descripancy between total demand and total supply was recognized, on the one hand, social pure consumption might be restrained so that non-production demand and total demand could be controlled and at the same time, social resource input in production might be raised,

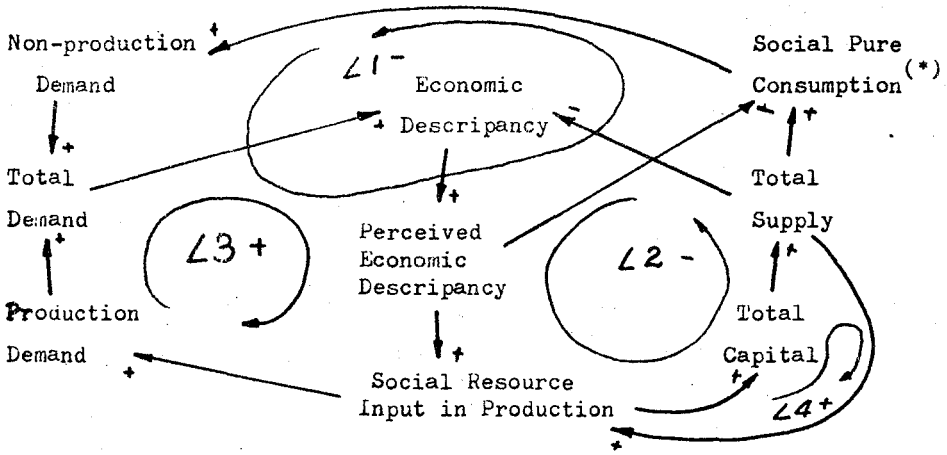

Fig.2 Basic Economic Growth Process.

total supply will increase, descripancy tends to disappear(feedback loop L1 and L2); on the other hand, because of an social resource increase in production, demand for resource may goes up, total demand will be extanded,new economic descripancy emerges(loop L3) . This situation appears frequently in socialist countries, where supply usually can not afford the demand. In the West, the situation is just the opposite because of the over supply. In general, when equilibrium of supply and demand exists, loop L4 will rule the system's behavior. But, equilibrium an as instant state, while the opposite state is a constant one.

Interaction Among Economy, R&D and Education

Growth economy emerges the need of R&D achievement, supplying R&D with social resources, mainly, budgeting & allocation of resource. Correspondingly, R&D gets the support from economy and contributes to it. Education system gets the funding from economy system, provides R&D with professionals and provides economy system with high quality labors(see Fig.3).

The greater the economic descripancy, the more the need to R&D achievement, and the more the R&D expenditure. The reason lies in: compared with capital and labor, R&D is a more active element in economic growth process.

* Including consumptions on R&D, education, etc..

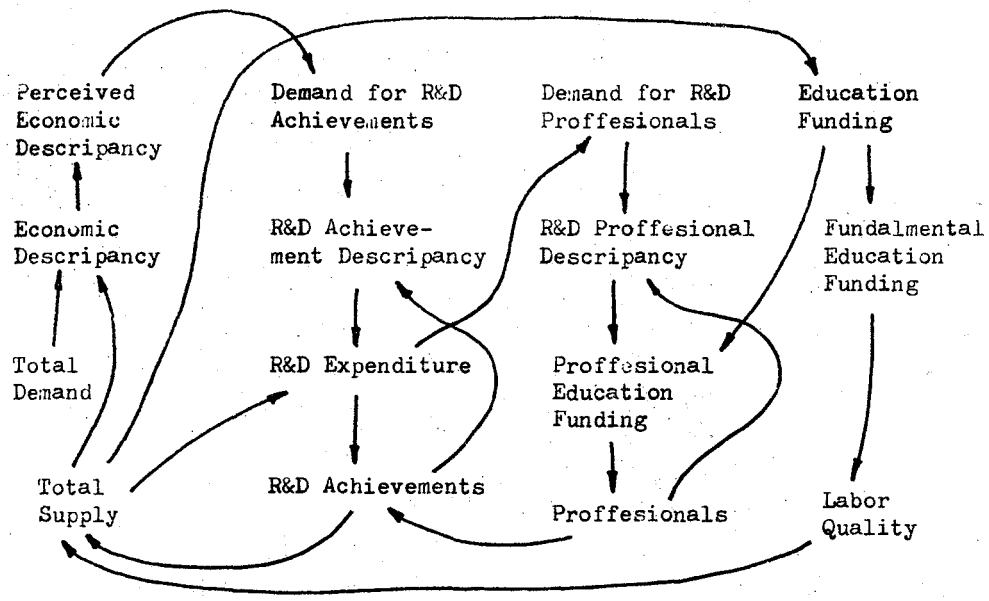

Fig.3 Interaction among R&D, Education and Economy.

Some critical equations in the model are as follows:

$$GRDE = NGRDE * PEG / AT \quad (1)$$

$$NGRDE = RDAD * ACERDA - RDELY \quad (2)$$

$$RDAD = NRDAED - SRDA \quad (3)$$

$$PEG = f(RDESLY, NGRDE, RDESCP) \quad (4)$$

$$RDESLY = RDELY / NI \quad (5)$$

Where:

GRDE -- Growth in R&D Expenditure

NGRDE -- Normal Growth in R&D Expenditure

PEG -- Possibility of Expenditure Growth

AT -- Adjustment Time

RDAD -- R&D Achievement Descripancy

ACERDA -- Average Cost of Each R&D Achievement

RDELY -- R&D Expenditure of Last Year

NRDAED -- Needed R&D Achievement Based on Economic Descripancy

SRDA -- Storage of R&D Achievement

RDESLY -- R&D Expenditure Scale of Last Year

RDESCP -- R&D Expenditure Scale Control Policy

NI -- National Income

Analysis of R&D Resource Allocation Policies

In SDRDA, R&D expenditure scale control policy provides the possible maximum

and the necessary minimum values according to theories of comparative superiority and scale-economy. In the basic run of this model, the maximum and minimum values are 1.0% and 4.0%, i.e., the annual R&D expenditure is about 0.01 to 0.04 of national income. Is this control policy available? See Tab.1.

Tab.1 Simulation Results under Different R&D Expenditure Scale Control Policies.

Policies \ Final Values of Main Indicators (*)	National Income (unit)	Returns on R&D Expenditure(%)	R&D Expenditure Scale(%)	Education Expenditure Scale(%)
The Basic (0.01, 0.04)	320(100)	5.88(100)	3.8(100)	2.56(100)
High Funding Policy(0.03, 0.06)	412(129)	4.55(71)	5.6(147)	2.94(115)
Low Funding Policy(0, 0.03)	292(91)	7.18(118)	2.4(64)	1.64(64)
"Laissez-faire" Policy on the Control of R&D Expenditure Scale(0, 0.16)	528(165)	4.0(63)	6.9(182)	2.92(114)

The implication from these modeling results:

- Unsuitable to existing R&D state, high funding policy deteriorate the reasonable proportion among B.R., A.R. and D., decreased the returns on R&D expenditure, although the national income final value increased a little.

- Although having a higher returns on R&D expenditure, low R&D funding policy does not benefit the national income.

- Set R&D expenditure scale control free, R&D and education funding will increase. This policy benefits the economic growth, but has a very low R&D returns on expenditure.

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* The rather theoratical term -- returns on R&D expenditure -- indicates the economic effectiveness of R&D resource. It equals the economic output of R&D over R&D expenditure.

III. SECOND MODEL----ALLOCATION RATIO MODEL(SDRDB)

Basic research, applied research and development have different functions in R&D process and complement each other. To raise R&D returns on expenditure and make completely use of the limited resource, B.R., A.R. and D. must coordinate with each other. Stressing on one is usefulless. SDRDB studies how to allocate properly R&D expenditure among B.R., A.R. and D. so that coordination in R&D process could be realized and high returns on expenditure may be achieved.

Three Stages of R&D

R&D can be seen as a process which composed of three stages(or types) , orderly, B.R., A.R. and D.. Generally, following stage is based on the achievement storage of foregoing stage, only when the achievement storage of foregoing stage is rich enough to match the following stage's need, the following stage then can work effectively; on the other hand, the effective demand of following stage to foregoing stage's achievement dominants the transient process of research results and the manpower as well as expenditure which the foregoing stage can be afforded. This relationship is the basis to coordinate B.R., A.R. and D.(see Fig.4).

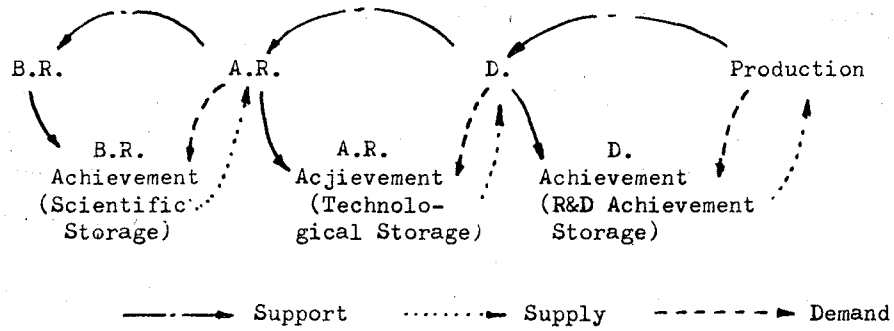

Fig.4 Three Stages of R&D Process.

Process of R&D Resource Allocation

Just as described above, the effective demand starts from economy system, passing through D., A.R. and B.R. respectively. Correspondingly,the order of R&D resource allocation process is the same. See Fig.5.

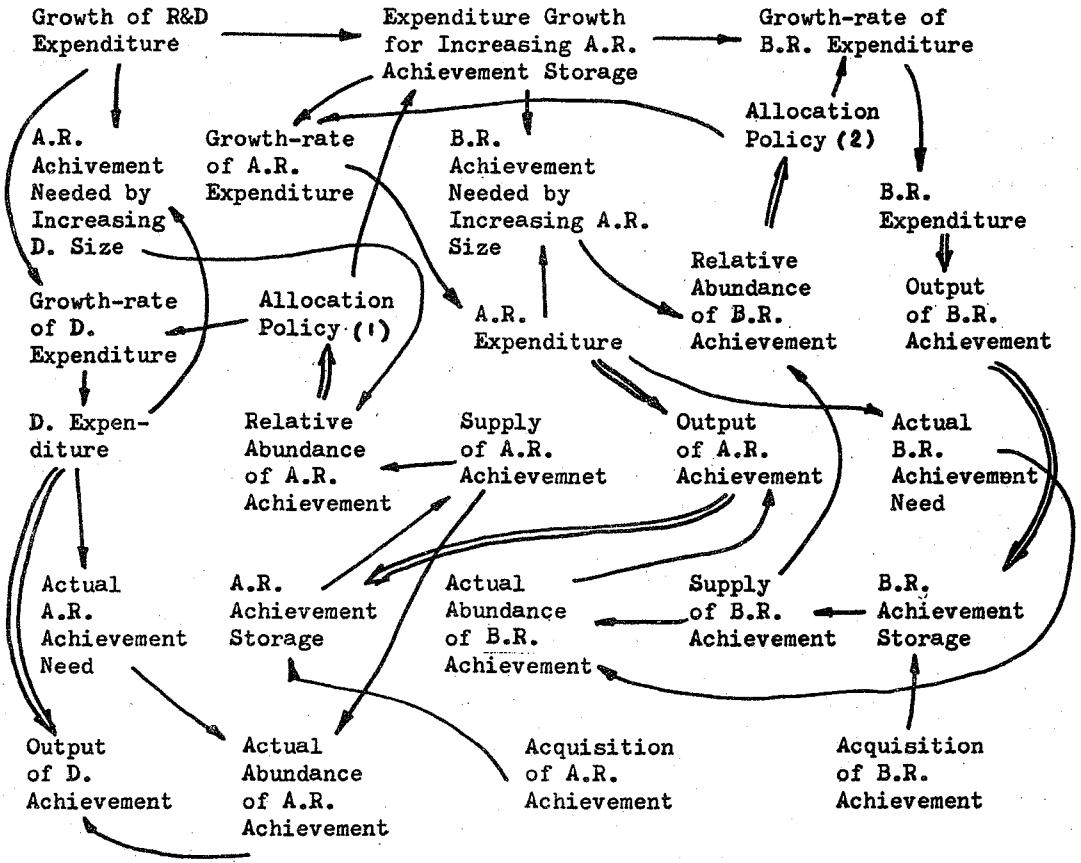

Fig.5 R&D Resource Allocation Process.

The process can be described as follows:

- According to relative abundance of A.R. achievement, when enlarging D. scale, decide how much of annual increasing R&D expenditure is needed for the enlargement and how much for increasing A.R. achievement storage;

- According to the coordinative situation of A.R. scale and B.R. achievement storage, when the expenditure for increasing A.R. achievement storage was known, decide the percentages of it for A.R. and B.R. respectively;

- Resource allocation policy changes the relative scales of different types of R&D, coordinates the development of R&D.

Resource allocation policy in SDRDB is: when annual increasing R&D expenditure is put completely into the following stage of R&D, see whether the foregoing stage's achievement is plenty enough to satisfy the following stage's need; if not, part of the annual increasing R&D expenditure will move to the foregoing stage.

Basic Behaviors of SDRDB

As mentioned above, scale of R&D expenditure is mainly decided by current social-economic situation. In order to analyze R&D resource allocation policies in different situations, we divided the industrialization and the development of national S&T into three stages based on the actual processes of principal developed countries. The characteristics of these stages are shown in Tab.2.

Tab.2 The Principal Characteristics of Three Stages in National S&T Development and Industrialization

Stages / Characteristics	The First Stage	The Second Stage	The Third Stage
Economic Goal	Strive for Economic Independance, Lay the Fundation to Develop.	Strenthen the Nation, Modenization Implementation.	Raise Life Quality, Economic Structure Rationalization.
Ways to Develop	Reproduction on an Extended Scale and Input of Labor and Money	Huge Capital Investment with Technological Innovation.	Technological Innovation, Development of R&D.
Gross National Products(GNP)	Week Strength, Developing Slowly	Developing Rapidly	Strong Strenth, Developing Steadly
R&D Resource Allocation	Small Demand and Scale of R&D, But Growth-rate of R&D Increase Rapidly.	As Demand for R&D Increased, Grow Rapidly.	Too Large Scale Compared with the Limited Resources and Grow Slowly.

From the viewpoint of above stages, let's study SDRDB's behavior as following(see Fig.6 and Tab.3).

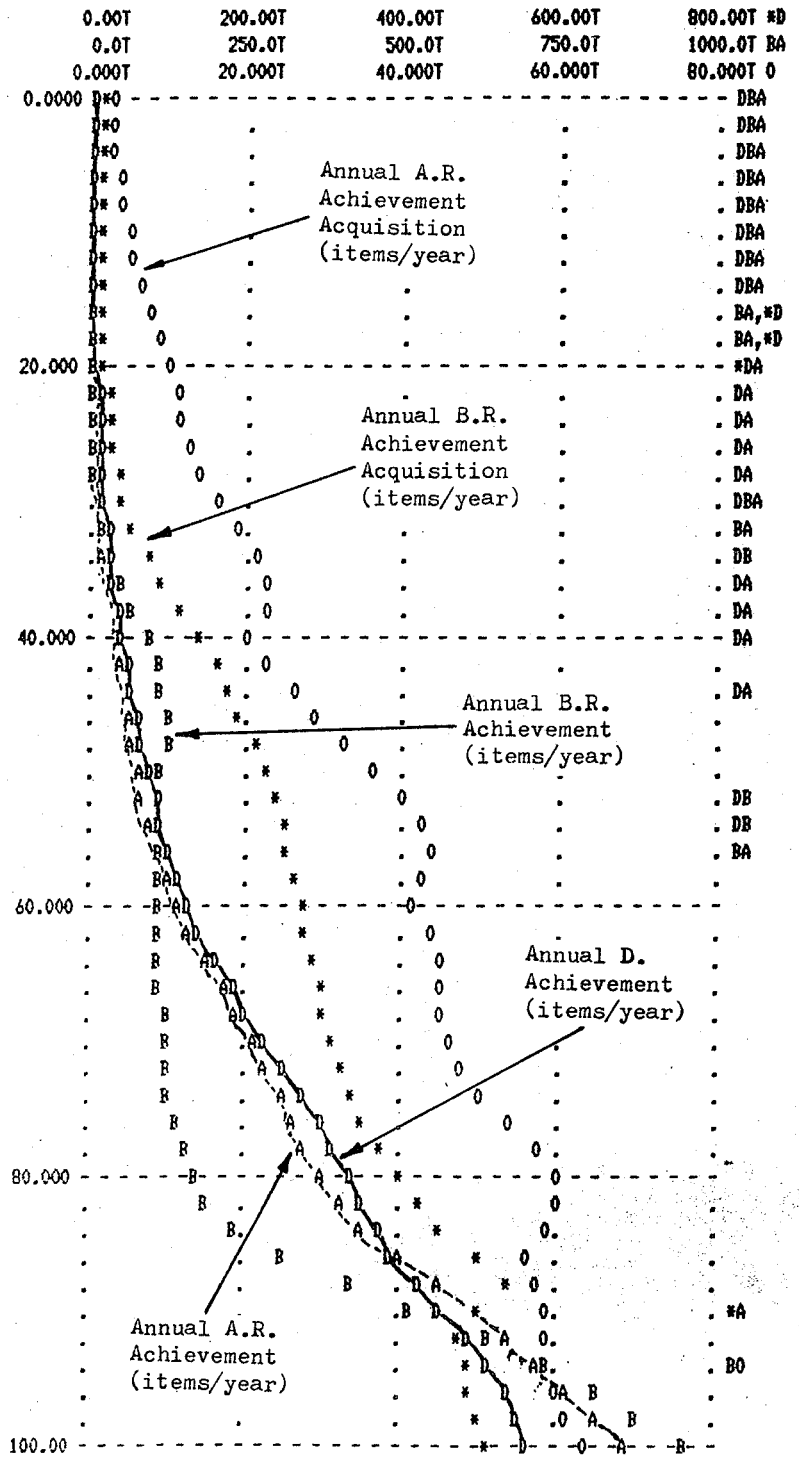

Fig.6(a) Basic Behaviors of SDRDB.

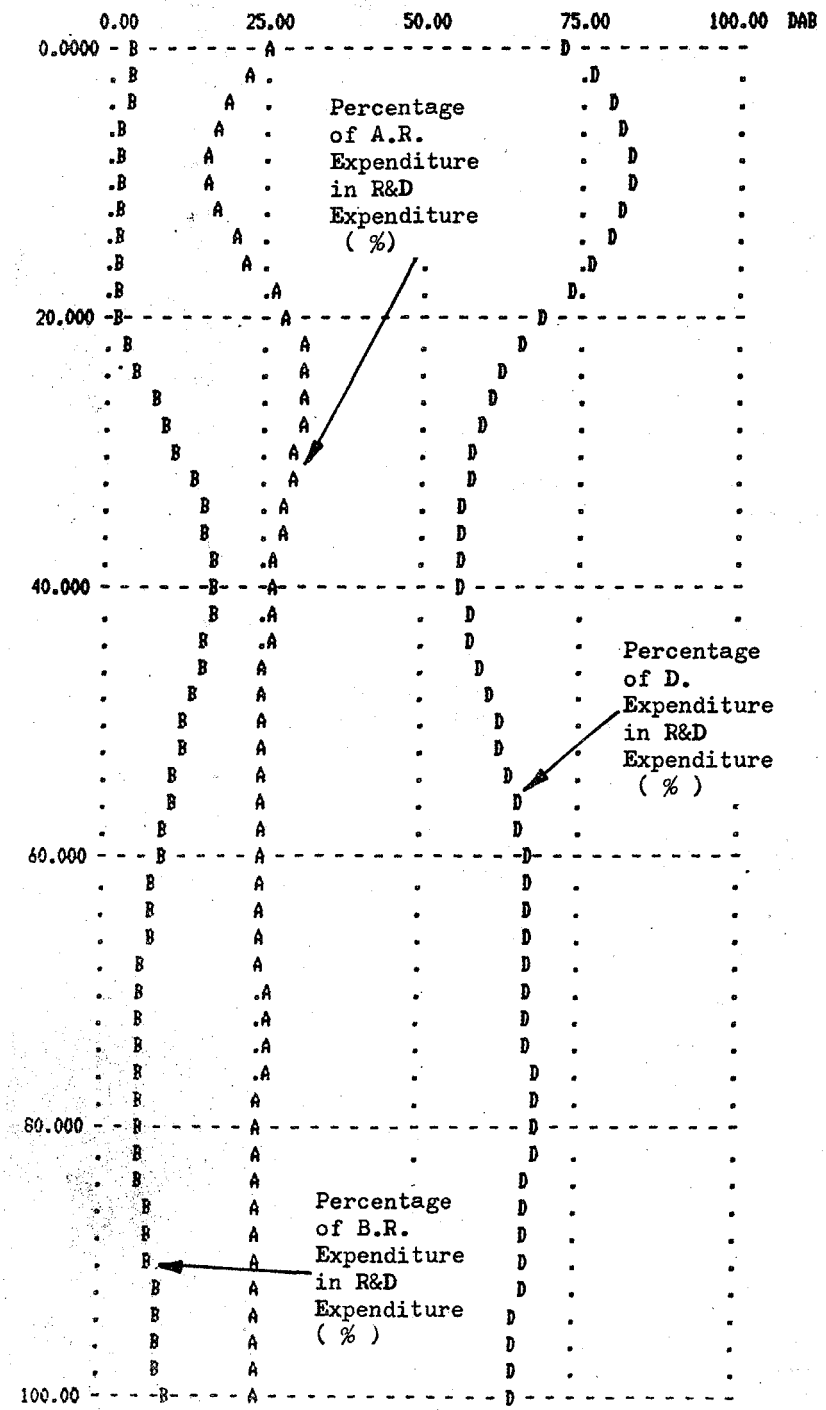

Fig.6(b) Basic Behaviors of SDRDB.

Tab.3 Basic Behavior of SDRDB

Stages / Characteristics	The First Stage (1st-20th years)	The Second Stage (21st-60th years)	The Third Stage (61st-100th years)
R&D Expenditure over GNP	0 - 1.0%	1.0% - 2.0%	greater than 2.0%
R&D Resource Allocation	Emphasising on Development	Developing A.R. and B.R. Rapidly	Stable Allocation with Proper Ratio among B.R. A.R., D.
Relationship between Technology Acquisition and Self-developing R&D	Acquisition of B.R., A.R. Achievement as Main Policy	Integration of these two Aspects	Self-developing R&D as Main Policy

R&D Resource Allocation Policy Analysis

As shown above, the system's basic behavior conforms to the historical development of most developed countries. It is believable that SDRDB is available for national R&D resource allocation process, because of the viewpoint of system dynamics that system's structure decides system's behavior, therefore, it can be used to test real world policies. We analyzed allocation priority policy, the proportional allocation policy, and the relationship between technology acquisition and self-developing R&D by using SDRDB, and the following results are given:

- R&D resource allocation ratio should be different in different stages of industrialization and development of S&T, so-called "optimal ratio" does not exist in the whole process of a country, except in the third stage, where existed a relative stable allocation ratio;

- In the ordinary case, abundance of scintific storage is the prerequisite for yielding continuously R&D achievement required by economy and developing national S&T. In any cases, basic research should be given

the priority for developing;

The technology acquisition policy plays different roles in different stages of industrialization. Generally, during the beginning phase of development, acquisition of A.R. achievement is more important; later on, the acquisition of B.R. achievement will be more important.

IV. POLICY SUGGESTIONS

According to the above analysis, some points should be paid more attention to in the R&D resource allocation decision-making process for our country.

The prerequisite to determine a proper R&D resource allocation scale is to recognize on which stage our nation is. There are many opinions of national resource allocation scale in comparing with the high ratio of R&D expenditure over GNP or national income in western countries. In fact, we are in the transient process from the first to the second stage of industrialization. In 1984, national R&D expenditure is only 1.255% of national income. After modeling and the analysis of actual data of many countries, such as Japan, FRG, etc., we found that the processes in which the values of R&D expenditure over national income changed from 1.3% to a higher stable value last around 10 to 15 years, no matter what the value is. Therefore, it is impossible for us to rapidly increase R&D expenditure and catch up with the developed nations in a short period of time. But, we must have a proper growth-rate of R&D expenditure, and in fact, this proper rate should be a little bit greater than the growth-rate of national income;

During the current stage of industrialization, we should pay more attention to applied research and development; in the meantime, increasing the expenditure on basic research, so that there will be an enough storage of knowledge and manpower available for continues development of S&T, which is important for economic growth. Currently, we have a much low basic research expenditure around 5% of total R&D expenditure which is not good for long-term economic growth;

Acquisition of applied research achievement is useful in recent years. But, blindly acquisition will be harmful to self-developing R&D, which is considered as the basis of national S&T development. More research should be conducted to find and fit a good proportional relationship between technology acquisition and self-developing R&D.

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