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Coordinative Development of the Social Systems by System Dynamics Modeling

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Abstract:

To develop continuably, it's important to keep the ecosystem balance. Coordinative development between the Economic System, Science & Technology System(S&T) and Education System, therefore, is also important, especially for China. It's an important national level policy decision issue.

This article first discusses the theory and mechanism of the sustainable and coordinative development of the three complex systems. Then are the nature and characteristics of the relationship between them analysed. Coordinative development can greatly enhances the competitiveness of a country.

Based on above theoretical analysis, this article advances a method of multicreteria optimization of coordinative development between the three complex systems.

The last, System Dynamics modeling is applied and policy analysis is made of growth rate on three systems for China. A brief conclusion was hereby drawn on the coordination of the development rate of S&T and Education. This conclusion was highly appreciated by some senior executives in the ministries.

Keywords: ecosystem balance, coordinative development, economic system, S&T system, education system, system dynamics, modeling approach, input

1 Introduction

At the turning point of another thousand ages, "Knowledge Economy" has been at the beginning of inkling, and the trend of global competition can not reverse too. Under above background and developing directions, how to grasp promptly the opportunities provided by knowledge economy, shorten the gap with Developed Countries (DCs), and increase international competitiveness of firms, industries and nation has become the great issues that China has to face at the turning point of 20 Century.

Bypast, the rapid development of science and technology to develop economy has brought the human a world of advantage, but synchronously, the abusive activity to environment has been repaid with serious ecological problems which become the impediment to develop economy sustainably. So many factors influence ecology as S&T, economy, as above, and demology systems. The rising of population not only consumes more rescue, but also produces more waste for environment to decompose (see figure 1).

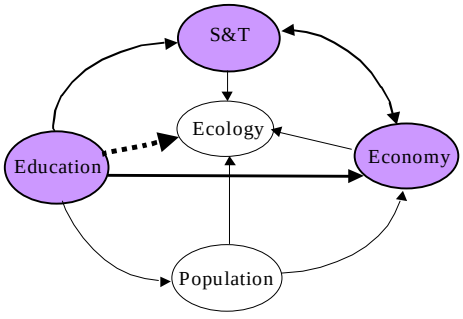


Figure 1 the five-system interactive frame

Now people come to know, only under sustainable environment can economy be developed sustainably. A subject thus is put forward on how to get environment sustainable, which is coequal important, if not more, with developing economy. Since the activity of S&T and economy has direct impact on environment, these two systems are undoubtedly the most important factors. Furthermore, as figure 1 shown, education can influence on ecology by influencing the activity of S&T, economy, and the population. So we can draw the following conclusion as, of the five systems, there exists a more basic interaction between S&T, economy and education. The coordinative development of these three systems becomes the precondition for ecology, even for all five systems to be sustainable.

On further thoughts, the solutions to all above issues have consanguineous relation with how S&T and education can be bring into economy, and how economy can support S&T and education activities strongly. Therefore, there is especial importance and theoretic value for China to survey the coordinative status among the three systems, and probe into the solution to reform. Furthermore, it is an important national level policy decision issue. For instance, coordinative development between the 3 complex systems greatly enhances the competitiveness of the Multiple-National-Companies (MNC), especially in the United States in the recent decades. Based on above reasons, the residual part in this article will be extended around the three systems, including the modeling by system dynamics.

2 the basic connotation of coordinative development of STEE

2.1 the nature and characteristics of the relationship between STEE

Knowledge becomes the principal resource at the knowledge and global era, and the most important mechanism is the production, distribution, application and diffusing of the knowledge. So, S&T and education become the most direct and pivotal activity to aim to it. But such activity in any country is carried under a sequential process, which need to face with the role transition and function adjusting. So it is important for S&T and education themselves to coordinate to take the new roles. On the other hand, S&T and education are seriously restricted by economic budget as well as promoting economic development. So, considering from the inner relationship, the coordinative development among the three systems become the sticking point whether S&T and education can promote economy and economy can improve the operating quality.

2.2 the connotation of the coordinative development among three systems

There is no structure without system, and no system without structure, either. The structure lies in every thing. On the other hand, the structure is related closely to another nature of system, which is interaction. The interaction between the factors in the system is carried through the structure formed by the factors, and the structure is the premise and base for the interaction.

Realizing from such point of view, the coordinative development of STEE can include following meanings:

First, to realize coordinative development, there must be inner coordinative in each subsystem, viz. inner structure is rational.

Secondly, on the base of rational inner structure in subsystems, the interactions between the subsystems are simulative

for each other in the process of getting to its aim.

Thirdly, the ultimate aim of coordinative development for three systems is the harmony as a whole, which concretely embodies in the optimization of holistic effect and structure matching.

2.3 a mathematics model of multicriteria optimization

Systemic analysis is a quantitative method to deal with coordinative development, which set up a model by the optimization analysis method in the condition of resource restricts. The big system of STEE is composed of three subsystems: S&T subsystem, education subsystem, and economy subsystem, which are marked by {ST}, {ED} and {EC}, each subsystem is composed of several factors. TE (Total Effect) defines the whole effect of STEE, so TE is the function of factors of subsystem, inner structure of subsystem, interaction between the subsystems, and interaction among the three systems, viz.:

$$TE=f(\{ai\},Si,Ii,TI),\ i=1,2,3$$

ai: the factors in the subsystem，i=1 refer to {ST}; i=2 refer to{ED}; i=3 refer to {EC};

Si: the inner structure of subsystem;

Ii ： the interaction between the subsystems;

TI：interaction among three systems

Above four variables can be classified by two kinds, ai and Si belong to structure, Ii and TI belong to interaction. So, the mathematical function of coordinative development among STEE can be figured as:

$$C=c(c1\{ai\},Si),c2(Ii),c3(TI))$$

c1({ai},Si) means rational inner structure of subsystems;

c2(Ii) means positive interaction between the subsystems;

c3(TI) means harmony on the whole.

Thus, on the base of x(0)=({ai(0)},Si(0),Ii(0)), four-leveled harmonizing and optimizing model can be set up as following:

First level: the first step of sectional harmonizing, rationalization of subsystem structure, S(x),

Second level: the second step of sectional harmonizing, positive interaction between the subsystems, I(x),

Third level: the third step of sectional harmonizing, positive interaction among three systems, TI(x),

Forth level: harmonizing as a mass, C(x),

Then, the optimize model can be described as a four-nested model as following(Figure 2).

Although it is difficult to work out this model, but it reflect a systemic thought to optimize step by step, and the logic relationship for harmonizing to improve step by step as well as the practical approach to obtain the coordinative development. As a tool to analyses the STEE coordinative development, it can provide directional and methodological reference for harmonizing STEE.

2.4 a successful example of harmonious development

Here, the Engineering Research Center (ERC) is a successful example, which typically testify the coordinative development and integration of STEE. ERC is a new cooperative form of industry, school, and research, which is based on university, hangs education and

$$\text{Max} \quad C(X^k) = c(C_1(S(X^k)), C_2(I(X^k)), C_3(TI(X^k))$$

$$\text{s.t.} \quad g_4(X^k) \le 0$$

$$C = C(X_{TI}^k),\ S = S(X_{TI}^k),\ I = I(X_{TI}^k),\ TI = TI(X_{TI}^k)$$

$$\text{Max } TI(X_{TI}^k)$$

$$\text{s.t. } g_3(X_{TI}^k) \le 0$$

$$C = C(X_I^k), S = S(X_I^k), I = I(X_I^k), TI = TI(X_I^k)$$

$$\text{Max } I(X_I^K)$$

$$\text{s.t. } g_2(X_S^K) \le 0$$

$$C = C(X_S^K),\ S = S(X_S^K),\ I = I(X_S^K),\ TI = TI(X_S^K)$$

$$\text{Max } S(X_S^K)$$

$$\text{s.t. } g_1(X_S^K) \le 0$$

$$C = C(X^{k-1}),\ S = S(X^{k-1}),\ I = I(X^{k-1}),\ TI = TI(X^{k-1})$$

$$when.k = 0, then.C(X^k) = C(X^0), S(X^k) = S(X^0), I(X^k) = I(X^0), TI(X^k) = TI(X^0)$$

Figure 2 A Four-nested Model

scientific research together, cultivates students during the research process, and students can absorb instructive experience in the cooperation practice. Such cultivate model of ERC not only provide mature technique and technology to the enterprise, but also bring up excellence talents with good adaptability and strong research ability to serve the development of S&T and economy.

3. The evaluation frame and international comparison on the coordinative development of STEE

3.1 the evaluation frame of the theory and mechanism

According to the connotation of the coordinative development of STEE, the evaluation accordingly lies in such three aspects:

(1) evaluating the rationality of inner structure of subsystem, by structure departure degree index and summed structure departure degree index;

(2) evaluating the interaction between the systems, by productivity rising indexes and bridge indexes;

(3) Evaluating the whole effect of STEE, by position departure index. The indexes are defined as:

$$\textit{The degree of structure departure} = \Sigma \left\| X_i - \overline{X} \right\|$$

Summed degree of structure departure = ∑(the degree of structure departure departure of system i)

X_i means the international place of each index; $\overline{X}$ means the mean value of international place of all the indexes.

i=1-3 respectively refers to the S&T system, education system, and economy system.

The less the index value of structure departure degree and summed degree, the more even the competence between the factors.

Productivity means that certain input can get more output because of technology progress, management improvement, or scale economy, such on. For one country, this index reflects the increase of economic benefit and improvement of matching between systems. The bridge index comes from such idea as the interaction between systems pass through the in-between, and several statistical and inquisitional indexes, elected from indexes system of international competence, can make up of bridge index and evaluate the degree of interaction and relation between systems.

Position departure degree =
|ST-ED|+|ST-EC|+|ED-EC|

Position departure degree describes the relative difference of developmental degree among the STEE, the value reflects the developmental status and change trend of coordinative degree of STEE as a whole.

This evaluation index's strongpoint lies in that, for one country, we can work out the degree of structure and position departure and bridge index of past years, which are tokens of the interaction between systems, to describe the change of coordinative developmental degree of STEE in the country. For different country, the comparison of such value between countries can explain the degree of native country relative to certain country, and analyses primarily where the weakness lies as well.

3.2 The international comparison on the coordinative development of STEE

The relative evaluation is based on the aforesaid evaluation index frame, and use the rational factors of international competence evaluation system for reference. When comparing, the countries can be separated into two groups, one is the developed country group represented by America and Japan, and another is the rising country group represented by Singapore and Korea. Then the evaluation frame can be applied to international and respective comparison. The conclusions include following several facets: STEE in developed countries are coordinative, which lies not only in the rational inner structure and the whole effect, but in the interaction and integration between systems and high degree of matching each other. Compared with developed group, the harmonious degree of the rising industrial countries and regions is not enough, but not large. The main challenge they faced with is to adjusting the economic structure and improving the adaptability of STEE structure. Meanwhile, they need to improve the interaction between systems.

The harmonious degree in developing countries is low and the harmonious status is poor. For China, it is not ideal in all the three aspects. The harmonious status is improved recently, but the structure of S&T and education in fact became more unreasonable, and the matching degree with economy became worse. It lies in the high degree of S&T and education structure departure, the high degree of summed structure departure of STEE, the high degree of the position departure of STEE, and the low value of bridge index.

The inspiration we can get from the comparison lies in that: economic benefit in one country is related directly to harmonious developmental degree of

STEE; there is two radical approaches to improve the absonant status of STEE, one is to optimize the structure of S&T and education, the other is to improve the bridge index, and promote the interaction among systems to evolve as a symbioses.

4. System Dynamics model of harmonious development among STEE in China

4.1 The virtues of System Dynamics approach to study harmonious development

System Dynamics (for short, SD) method is an effective one in describing the structure, the interaction and evaluative activity of complex systems, since the structural relationship formed by SD model decide directly on systemic function. Namely, the dynamic model is built upon inner structure, stream of matter, stream of information, and their feedback structure, then provide the practical possibility for explaining the systemic dynamic activity.

Comparing with theoretic optimization method, SD method has following strongpoint. (1) For non-linear complex system, SD method can improve systemic activity more roundly by transferring the problem from outside system to inside which changes the systemic structure and activity model deeply. (2) Herein systemic evolution activity is uncertain, SD method can show the process all-around through simulating and improve effectively the certainty and intuitivism. (3) More obviously, SD method can deal with large number of data which theoretic method can't do.

4.2 The SD model of STEE

The model can be separated into several models, including the whole structure, the subsystem structure of S&T, education, and economy.

In the whole model, the interaction and multileveled feedback relationship among three systems decide on the characteristic of holistic activity. The whole structure of the model is showed as figure 3.

There are three interrelated feedback loops representing the interaction between three systems. The loop Ⅰ describes the inter-promoted relationship between education and economy. The loop Ⅱ describes the relationship between S&T and economy, and the loop Ⅲ describes the one between S&T and education.

On the basis of whole structure, we can grasp the further causality in each subsystem by systemic analysis approach, which are showed as figure 3 to 5, and get the respective SD flow chart eventually.

4.3 the SD flow chart of the model

According to the structure of system model above, the SD flow charts of the model can be drawn out. Figure 6 is about the economic subsystem and its abbreviative meaning of the variables listed in table 1, the others just follow it.

Figure 2 Whole structure relationship of interaction among STEE

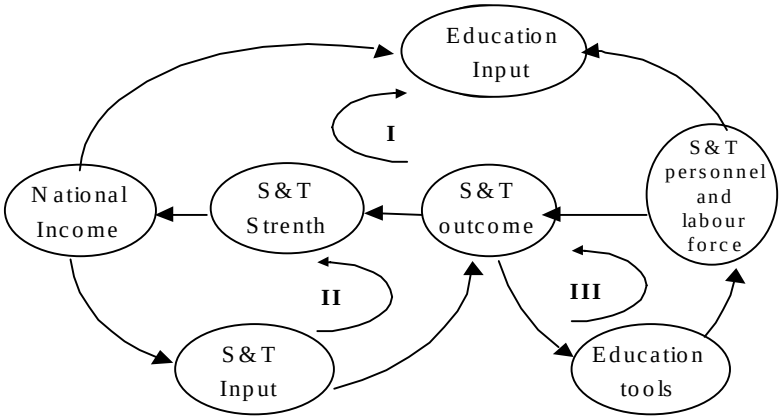


Figure 3 the causality of education subsystem

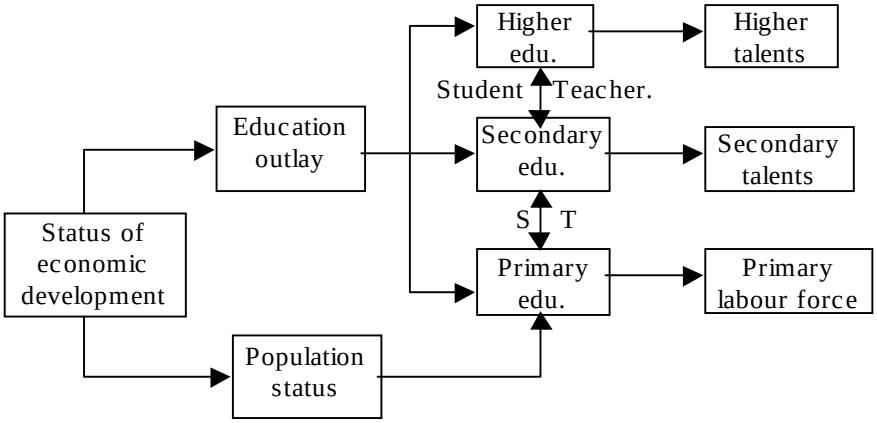


Figure 4 the causality of S&T subsystem

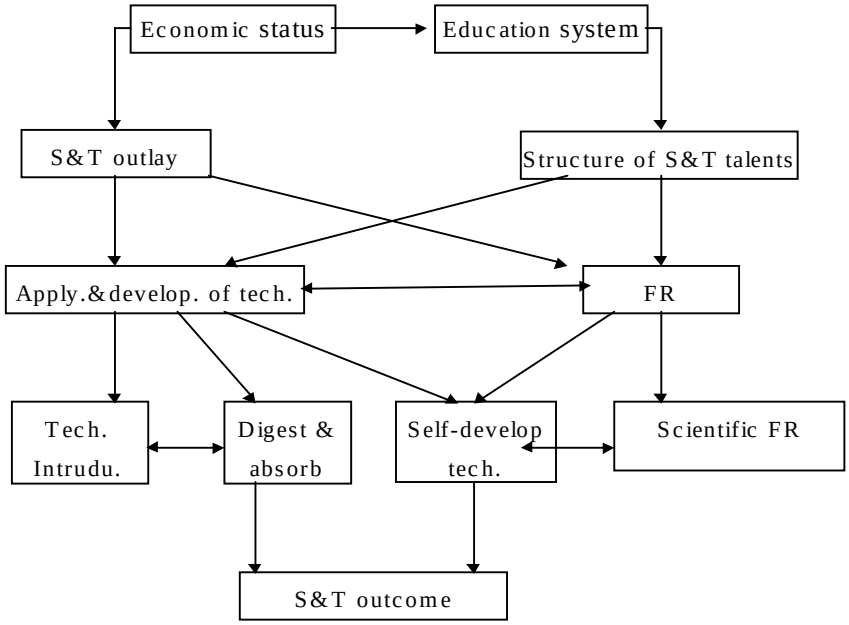


Figure 5 the causality of economy subsystem

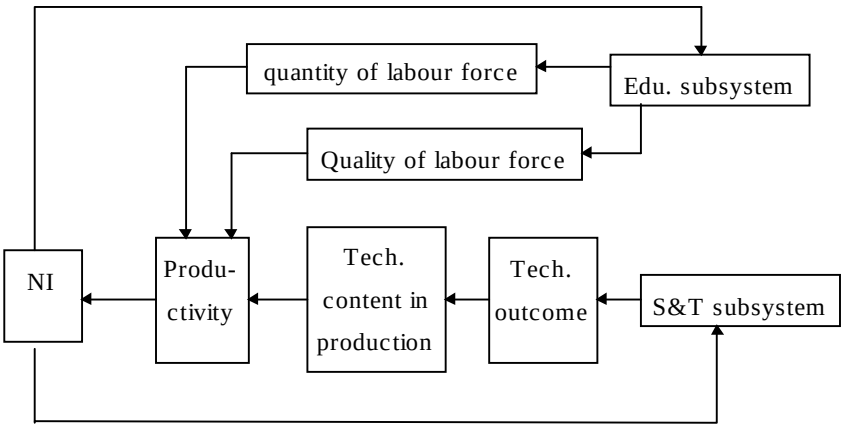


Figure 6 the SD flow chart of the economic system

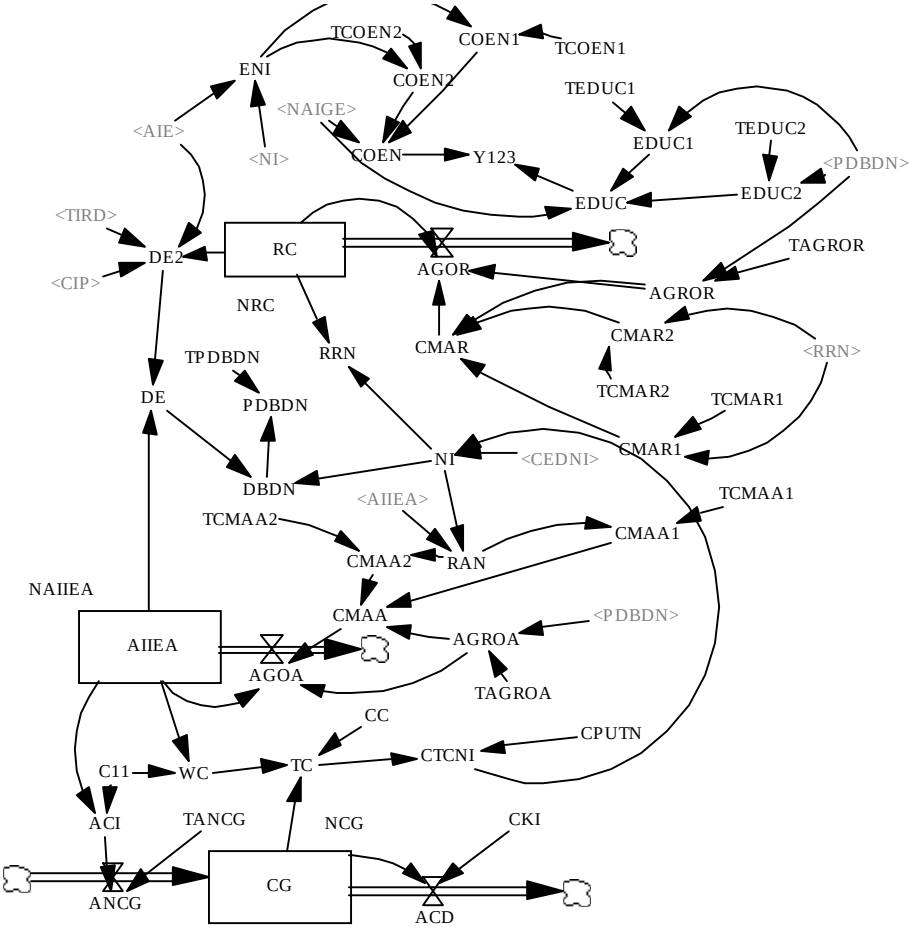


Table 1 the corresponding of variables in economy subsystem model

ACD	Annual fixed assets discount	ACI	Annual input of fixed assets
AGOA	Annual growth of economic input	AGROA	Annual growth rate of economic input
AGOR	Annual growth of economic consumption	AGROR	Annual growth rate of economic consumption
AIIEA	Annual economic input	ANCG	Annual growth of fixed assets
C11	The proportion of fixed assets to economic input	CC	Annual average liquidity time of current assets
CG	Fixed assets	CK1	Annual discount rate of fixed assets
CMAA	Annual growth rate of economic input restricted by resource	CMAR	Annual growth rate of consumption restricted by resource
CPUTN	Unit economic benefit of aggregate assets	CTCNI	Contribution of aggregate assets to national income
DBDN	Economic Difference	DE	Aggregate demand
N1	Economic input being the upper limit of aggregate supply	N2	Economic input being the lower limit of aggregate supply
N3	Pure consumption being the upper limit of aggregate supply	N4	Pure consumption being the lower limit of aggregate supply
NAIIEA	Initial value of annual economic input	NCG	Initial value of fixed assets
NI	National income	NRC	Initial value of pure consumption
PDBDN	Realized economic difference	RAN	Proportion of economic input to national income
RC	Pure consumption	RRN	Proportion of pure consumption to national income
TANCG	Average time of fixed assets	TC	Aggregate assets
TPDBDN	Lag time for society to realize economic difference	WC	Liquidity capital

5. The multicriteria optimization based on SD model

5.1 the basic concept of optimization method by SD

Here is another method by SD, which fits well for policy analyzing. To evaluate the solutions proposed, it goes by two steps. First, elect some basic indexes in order to make evaluation. Secondly, compare the future value of indexes for each solution by simulating, and attempt to achieve the best possible result during the dynamic process.

For STEE, education input and S&T input may be regarded as devoted variables, different input choice makes different solution. Electing such indexes as Gross national product (GDP) reflecting economic level, number of S&T personnel (STP) reflecting educational level, total factor productivity (TFP) reflecting S&T level. Thus GDP, STP, TFP constitute basic index system and can be used to evaluate the harmonious degree of STEE. After inputting the existing input data to SD model, some index value for future will produce, and the value group of GDP, STP and TFP will differ from different solution. Then we can compare the value groups and get the best corresponding solution, which we may act on.

5.2 the evaluating and optimizing process of three indexes

There are four kinds of increase patterns about the input of education and S&T.

Pattern 1: the proportion of input to GNP or NI is fixed and increases

following the economy,

Pattern 2: this proportion increases at a fixed speed,

Pattern 3: the proportion increases at a low speed first, then high-speed, in the end the proportion holds the line.

Pattern 4: the proportion increase with high-speed at first, then holds the line for some time, then slow down until get to a steady value.

Thus, there are 16 patterns combined as Table 2 listed.

Table 2 the 16 patterns combined by education input and S&T input

S&T input / Edu. input	P 1	P 2	P 3	P 4
P 1	P11	P12	P13	P14
P 2	P21	P22	P23	P24
P 3	P31	P32	P33	P34
P 4	P41	P42	P43	P44

Then, for each pattern, the simulation outcome of GDP, STP, TFP and the evaluation of optimization can respectively be achieved as Table3-5.

Table 3 evaluation on index of GDP

Combination pattern	1997	2007	2017	2027	2037	2047	Evaluation on feasibility
P11	75.3	87.5	88	82.5	68	71.2	-
P12	75.3	97	98	84	71	73	-
P13	75.3	93	153	145	93	108	-
P14	75.3	88	130	152	123	150	+
P21	75.3	150	175	163	133	147	-
P22	75.3	108	162	202	175	204	+
P23	75.3	123	162	198	198	213	+
P24	75.3	146	187	206	194	204	+
P31	75.3	119	198	213	160	180	-
P32	75.3	102	228	295	260	268	++
P33	75.3	181	173	158	150	180	-
P34	75.3	133	250	273	240	245	++
P41	75.3	92	154	177	165	194	+
P42	75.3	113	181	238	175	227	+
P43	75.3	98	135	192	200	177	-
P44	75.3	127	193	360	392	390	+++

Table 4 evaluation on the index of STP

Combination pattern	1997	2007	2017	2027	2037	2047	Evaluation on feasibility
P11	83.44	101	97.5	72	57	67	-
P12	83.44	111	117	100	80	86	-
P13	83.44	135	142	120	90	99	-
P14	83.44	113	137	153	140	155	+

Table 4 evaluation on the index of STP (Continued)

P21	83.44	130	162	170	135	157	-
P22	83.44	122	155	175	142	165	+
P23	83.44	115	150	177	152	190	-
P24	83.44	170	158	170	167	173	+
P31	83.44	175	183	150	140	138	-
P32	83.44	117	208	248	233	238	++
P33	83.44	198	215	170	123	156	-
P34	83.44	102	144	190	202	196	++
P41	83.44	106	144	196	181	181	+
P42	83.44	138	168	185	188	168	-
P43	83.44	135	169	167	154	190	+
P44	83.44	90	220	327	323	340	++

Table 5 evaluation on the index of TFP

Combination pattern	1997	2007	2017	2027	2037	2047	Evaluation on feasibility
P11	29.6	37	36	28	23	25	-
P12	29.6	44	48	35	23	26	-
P13	29.6	62	50	38	35	32	-
P14	29.6	52	58	55	42	45	-
P21	29.6	42	58	60	42	47	-
P22	29.6	50	65	70	42	70	+
P23	29.6	46	63	73	54	69	-
P24	29.6	44	65	80	80	77	+
P31	29.6	56	69	60	38	52	-
P32	29.6	35	82	88	70	82	+
P33	29.6	42	75	70	52	60	-
P34	29.6	40	53	63	80	73	++
P41	29.6	42	58	73	38	65	+
P42	29.6	60	68	65	63	65	-
P43	29.6	40	63	77	52	65	-
P44	29.6	33	46	63	80	80	++

Based on above evaluation on single index respectively, the total evaluation may be listed as Table 6.

Table 6 total evaluation on three indexes

Pattern	P11	P12	P13	P14	P21	P22	P23	P24
evaluation	-	-	-	+	-	+	-	++
Pattern	P31	P32	P33	P34	P41	P42	P43	P44
evaluation	-	+++	-	++++	+	-	-	+++++

The simulating result suggests that P24, P32, P34 and P44 are feasible.

5.3 the policy meaning of the model

Since the actual condition in China lies that the development of S&T and education lag badly behind the development of economy, which makes a high demand to S&T and education, so to their input. Pattern 44 can be proved best one, and the concrete distributive strategy of S&T and education input lies in the fifth column in Table 7.

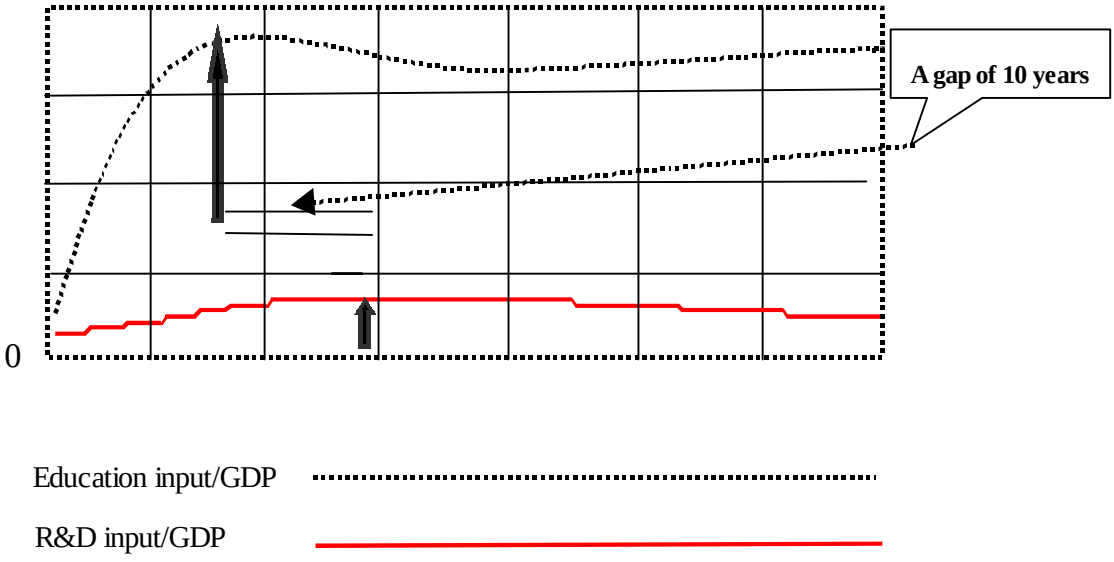
Table 7 different demand among four feasible combination patterns

	P24	P32	P34	P44
Distributive strategy in R&D	FR: 2016' 9%; 2045' 7.5%; AR: 2001' 29%; 2045' 24.5%; ED: 2045' 67.9%;	FR: 2045' 23%; AR: 2010' 28%; 2045' 34%; ED: 2045' 439%;	FR: 2045' 26%; AR: 2045' 38%; ED: 2045' 36%;	FR: 2036' 19%; 2045' 18%; AR: 29-30%; ED: 2045' 52%;
Distributive strategy in education	PE: 2045' 50% ME: 29-30% HE: 20%	PE: 2021' 44%; 2045' 47%; ME: 24% HE: 2036' 29%; 2045' 28%	PE: 2045' 42% ME: 24% HE: 33%	PE: 2010' 39%; 2045' 46%; ME: 29-30% HE: 2016' 29%; 2045' 26%

FR: fundamental research; AR: applied research; ED: experimental development; PE: primary education; ME: middle education; HE: high education。

Furthermore, it is concluded by SD that education input had better 10 years ahead of S&T input. The figure lies as following.

Figure 7 education input ahead of S&T input development



Summary

By SD we can draw a conclusion as that, education input had better 10 years ahead of S&T input in China. Such arrangement on input can be in favor of developing S&T, Economy and Education harmoniously and sustainably, so to Ecology. This conclusion was highly appreciated by some senior executives in the ministries.

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