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A System Dynamics Model for Predicting Supply and Demand of Medical Education Talents in China

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ABSTRACT
The purpose of this paper is to study the relationship between the demand for medical talents in China and the supply of talents in medical colleges and universities. Predicting the future development of medical talents is of great significance to the establishment of medical education and the cultivation of medical talents. Based on data from China Statistical Yearbook and OECD 34 countries from 2010 to 2014, as well as some research results on overseas and domestic scholars, a system dynamics prediction model relating the supply and demand of medical education talents is developed in this paper. Actual data for the Jiangsu Province is used to demonstrate the correctness, validity and applicability of the model. Simulation results show that, under the current conditions and political environment and to maintain the current average levels of OECD 34 countries, the projected number of demand for doctors in Jiangsu in 2024 is a little more than 319,800. Based on current data, there is still quite a large gap between these indexes in China and the desired target levels. Consequently, the system and structure of medical education need to be adjusted, with the corresponding policies and management system simultaneously reformed and medical environment improved.

Keywords: demand and supply, prediction, medical education talents, system dynamics model

INTRODUCTION

Medical and health services are major livelihood issues affecting the health of hundreds of millions of people and the well-being of millions of households. Research on planning, prediction and management of medical talents has become a hot topic in academia. At present, with the rapid acceleration of industrialization in China along with the fast-paced urbanization and improvement of people's living standard, there is an increasingly rising demand for improved medical and healthcare services. Moreover, a huge upsurge in the variety and number of ailments (diseases, injuries, disorders, etc.) has placed tremendous pressure on the already stretched healthcare delivery systems. Worst still, loss of medical students (due to retention problems and loss of interest), which subsequently triggers shortage of medical talents, has begun to cause widespread concerns in the public and private sectors as well as within the population at large and overextended medical workers. To help relieve the current status, the need to stay in front of the talents curve is becoming increasingly critical given the dynamics of the current medical

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State of the literature

- Various approaches have been applied to deal with the problems of predicting talent demand. These include factor reconstruction analysis and elastic coefficient forecast method, neural network models, grey theory, support vector machine (SVM) model and improved (accuracy) forecasting techniques. These approaches mostly focus on parts of the problem. The existing approaches listed are not adequate to mount effective responses, as the medical talent demand and supply problem is indeed a complex system which is influenced by many complex factors.
- System Dynamics (SD) is well suited to address complex dynamic prediction problems. SD has been applied in some studies to analyze the cost factors effects on cost of quality, to explore policy options for improving neonatal health and to analyze the influence factors of enterprise cluster complex network resources integrability. But it hasn't been found to predict in medical education talents.

Contribution of this paper to the literature

- The existing literature doesn't take into account the complexities of the problems of predicting talent demand. The research presents the need to take into consideration the complex dynamics of the medical talent demand and supply system, and the complex interconnections of the various influencing factors.
- The existing literature mostly focus on parts of the problem to predict the talents. The present research applies the systematic thinking to predict the medical education talents and medical talents.
- The research builds a system dynamics model for predicting supply and demand of medical education talents, the model can make more accurate forecast of the medical education talents than other methods.

talent pool. A possible solution is to reform of the medical education system using a good long-term forecast of the supply and demand talents.

Current Demand and Supply of Medical Education talents

Demand: Present Situation of Medical talents

In this paper, medical doctors refer to licensed (assistant) physicians in the health technical personnel pool. According to Zhang (2013) and National Bureau of Statistics of China (2015), it is known that the total amount of human capital in China's health industry has been increasing continually. The number of medical technical personnel has increased from 4,490,803 in 2000 to 7,589,790 at the end of 2014, and the number of doctors in hospital has increased from 1,603,266 in 2000 to 2,374,917 in 2014. From the point of view of education level, the ratio of the number of health technical personnel with college degree or above has increased from 27.2% in 2000 to 69.5% in 2014. The average years of schooling has increased by 1.4 years. Although the human capital in China's medical and health industry have expanded rapidly, there are still many problems. First, the present total amount of health technicians in China is insufficient, and the average number of China's licensed (assistant) doctors per thousand people in 2014 was 1.7 (see **Figure 1**) from data prepared by OECD (2014), which is lower than 3.2 that is the average level of OECD 34 countries. Second, with the number of registered nurses per thousand people being 2.2 in 2014 (see **Figure 2**) from data prepared by OECD (2014), the doctors to nurses ratio in China in 2014 was 1: 1.29, which is seriously imbalanced and is lower than 1:2.47 that is the average level of OECD 34 countries. It is even lower than 1:2 that is the ideal minimum standards recommended by WHO. In accordance with the geographical area distribution, Anand et al. (2008) applied Gini coefficient to obtain the Gini coefficient of the national distributions of doctors and nurses, respectively as 0.362 and 0.471. This indicates an urgent need to improve the ratios of internal structure of China's health technical personnel. Third, the proportion of total health expenditure as a percentage of GDP in China is far lower than that of developed countries. The percentage of total health expenditure in 2014 was 5.55%, which was lower than that of Brazil in 2011 (8.8%) and South Africa (9.2%). China's per capita total health expenditures in 2014 of $379.6 is much lower than the United States per capita total health expenditures in 2009 of $7960. China's government health expenditures per capita in 2014 of $130 is also far lower than that of United

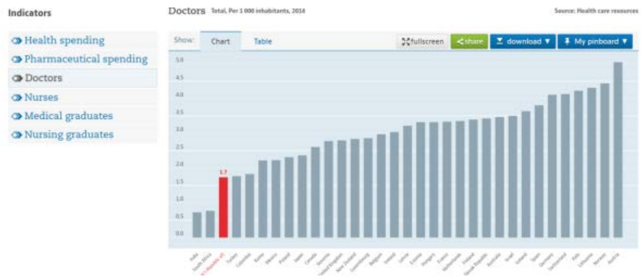

Figure 1. Number of talents per 1000 population in 2014

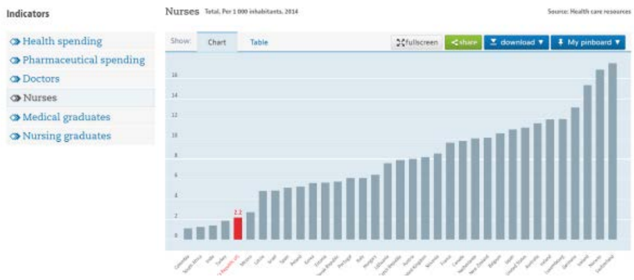

Figure 2. Number of nurses per 1000 population in 2014

States in 2009 of $3795. Finally, the education level of health technical personnel needs to be markedly improved. The average years of schooling of Chinese medical personnel in 2014 was 14.1 years, among which, technical secondary school accounted for 28.2%, college degree 38.9%, and bachelor degree or above 30.6%. On the contrary, the practice of medicine in the United States must be qualified with doctor's degree and long internship.

According to Zhang (2013) and National Bureau of Statistics of China (2015), it is known that: China's medical enrollment has been growing continually. The number of medical professional enrollment in colleges and universities had increased from 75,000 in 1998 to 606,000 in 2014; and the number of medical professional enrollment in secondary vocational school had increased from 169,000 in 1998 to 488,000 in 2014. In the same period, the number of college degree programs with medical and pharmaceutical majors had increased from 93 to 188, with the number of colleges offering these majors being 103 undergraduate colleges and 85 academies. This shows a rapid development in enrollment specialty. However, the level of medical education enrollment is still relatively low, and the enrollment ratio of undergraduate college to junior college had dropped from 1.5:1 in 2000 to 0.67:1 in 2014. In particular, the enrollment growth of corresponding undergraduate of western medicine was about 50% lower than that of junior college. However, the medical training scale in secondary vocational schools had expanded excessively relative to college-level medical training. In 2014, the medical enrollment ratio of ordinary universities to vocational colleges was 1.39:1. Among medical-related training enrollments in 2014, 6.05% was at the masters' level or above, 20.67% at undergraduate level, 31.4% at the junior college level, and 41.9% at the vocational level. Clearly, the training levels and the qualifications of many health professional and technical personnel cannot meet the requirements of the higher end medical talents required. In addition, due to the imbalance of economic development, many medical graduates do not want to go to the local health service organizations, and they would rather change the direction of employment rather than being forced to go remote healthcare delivery organizations. This obviously result in further large loss of medical students.

It can be seen from the above analysis that the health technical personnel situation in China needs to be urgently upgraded, both in number and in training levels (qualifications) to meet the rapidly growing demand of medical talents in the next decades. At the higher level, medical education policies and management system have to be reformed, and medical environment improved to attract and retain medical students and to encourage medical graduates to continue practicing medical professions. Finally, the system and structure of medical education need to be adjusted to accommodate the necessary expansion of medical students and to upgrade medical education to produce upper-level medical talents to meet the growing demand. Therefore, predicting the demand and supply of medical talents is of great practical significance to the development of health service and medical education in china.

Recent Approaches to Predicting Talents

Various approaches have been applied to deal with the problems of predicting talent demand. These include factor reconstruction analysis and elastic coefficient forecast method (Wang et al.,2000; Yu et al., 2004), neural network models (Wu et al., 2004), grey theory (Wang et al.,2010; Wang, 2010; Gao et al., 2017), support vector machine (SVM) model (Zhang et al.,2011) and improved (accuracy) forecasting techniques (Eric,2016). These approaches mostly focus on parts of the problem. However, it has been increasingly recognized that a new approach that takes into account the complexities of the medical talent demand and supply problem is urgently needed. The existing approaches listed are not adequate to mount effective responses, as the medical talent demand and supply problem is indeed a complex system which is influenced by many complex factors. This presents the need to take into consideration the complex dynamics of the medical talent demand and supply system, and the complex interconnections of the various influencing factors.

System Dynamics (SD), as a modeling and simulation tool of dynamic systems, was developed by (Forester,1961). It is well suited to address complex dynamic prediction problems (Ge et al., 2014). It allows scenario analysis and policy analysis to be performed with ease. The only requirements for SD to work well are that causality relationships among various variables and factors must be well understood to allow the development of system equations (differential or difference equations) describing the dynamics of the system, and that data must be available to allow accurate calibration the model. SD has been applied in some studies to analyze the cost factors effects on cost of quality (Behdad, 2009; Mi et al., 2015), to explore policy options for improving neonatal health (Agnes et al., 2016).and to analyze the influence factors of enterprise cluster complex network resources integratability (Xiao, 2013; Mi et al., 2016). AS mentioned above, The medical talent demand and supply system is complex (consisting of many interrelated parts including feedbacks) and dynamic whose causality is fairly well understood, and whose calibration data are readily available in the case of Jiangsu Province, China. It is precisely these reasons that Systems Dynamic will be used to develop a simulation model and to perform the necessary prediction and policy analysis.

MATERIAL AND METHODS

System Dynamics Model of Supply-Demand of Medical Education Talents

Model Structure, Scope and Assumptions

Since the purpose of the model is to predict the balance between supply and demand of medical talents in China, the model will focus on three core subsystems and those and only those factors that have significant impacts on at least one subsystem. The three subsystems are

- the population subsystem, which is the key driver of supply-demand for medical talents,
- the medical student subsystem, which represents the supply side of medical talents,
- the healthcare delivery subsystem, which represents the demand side of medical talents.

In addition to natural birth rate and mortality rate, key factors that have significant impacts on the supply and demand of medical talents include, but not limited to, government policies (e.g. target number of doctors per 1000 people, etc.) and investment, actual number of enrollment in medical- and health-related fields, graduation and retention rates, and job market in medical and health related fields. These define the scope of the model.

We will build a continuous version of the dynamic model using the quantity balance principle, although conversion to a discrete version for the actual numerical (digital) computation is relatively easy using Euler's method of integration. Time delay will be used when appropriate. For example, the number of graduates from a 4-

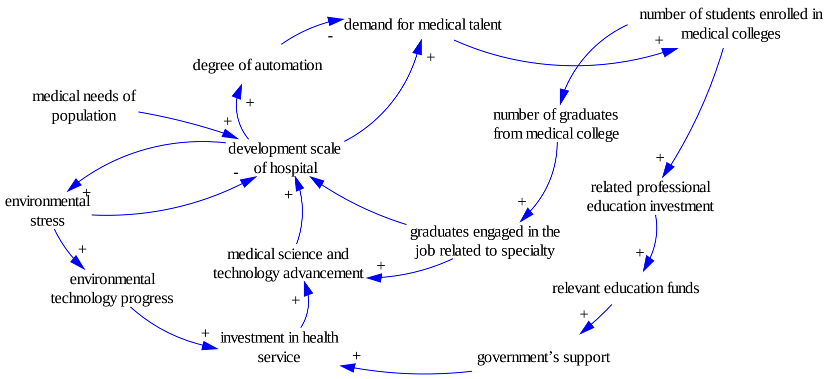

Figure 3. Causal relationship diagram of demand and supply of medical talents

year college in a certain year depends, among other things, on the number of entering students four years earlier. We will assume that, once enrolled, a student will stay in college until graduation. Finally, we assume that medical doctors only come from the pool of medical graduates from medical colleges and academies, and do not come from any other sources.

Causality Analysis

The complex interactions of factors that significantly affect the supply and demand of medical talents can be best displayed using an influence diagram as shown in **Figure 3**. Since all "influences" appearing in the diagram appear to be causal (not just correlation), **Figure 3** can also be viewed as a causal relationship diagram.

Focusing on the demand (demand for medical talents) and supply (graduates engaged in the job related to specialty), there is a core loop that links them through the growth of national healthcare system (development scale of hospitals). The loop begins with the "demand for medical talents". An increase/decrease in the demand will induce a similar change (in sign) of the following factors consecutively: (1) the number of students enrolled in medical colleges, (2) the number of graduates from medical colleges, (3) the number of graduates engaged in the job related to specialty (supply), and finally (4) the growth of national healthcare system (development scale of hospitals). The last connection that closes the loop is the influence of the growth of national healthcare system on the demand itself. This influence occurs in two paths. First an increase/decrease in the growth of national healthcare system directly induces a similar change (in sign) in the demand for medical talents. On the other hand, the growth in national healthcare systems will most likely induce the growth in medical robotic technologies (degree of automation) thereby reducing the needs for human medical doctors. These two paths are in opposite directions, one positive and one negative. If the net effect is positive, then the entire loop is a positive feedback loop which will induce unbounded growth if it remains unchecked. On the other hand, if the net effect is negative, it will induce a stabilizing level of demand in the long-term. Here is where scenario analysis can be performed to produce insights that would be useful in formulating national strategies and policies on national healthcare system and medical education. The remaining parts of the diagram show how the national growth in the national healthcare system (development scale of hospitals) is influenced by factors that are related to national healthcare policies and investments (as well as factors due to population growth). For example, an increase in investment in health services should lead to an advance in medical science and technology, which will in turn lead to growth in the national healthcare system. The remaining influences can similarly be deduced.

System Equations for the Supply and Demand of Medical Education Talents

Based on the causality analysis in **Figure 3**, we can now develop a more detailed system dynamics model relating the supply and demand of medical talents as shown in **Figure 4**.

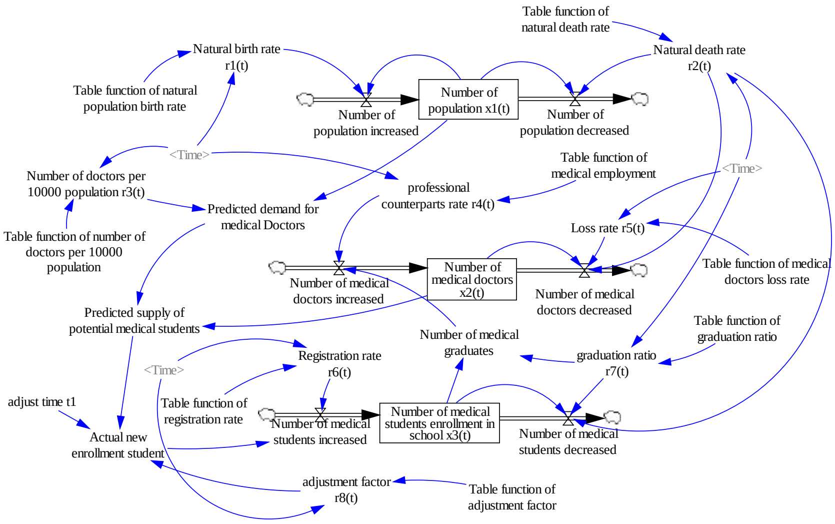

Figure 4. A system dynamics model of the supply and demand of medical education talents

In order to describe the dynamic relationships in the model, we first define the following state/block variables and constants:

State/Block Variables:

$x_1(t)$: Number of thousands of healthy population at the end of year t

$x_2(t)$: Number of medical talents available at the end of year t

$x_3(t)$: Number of medical students enrolled in medical colleges at the end of year t

Parameters (constants):

$r_1(t)$: Natural birth rate of the population in year t

$r_2(t)$: Natural death rate of the population in year t

$r_3(t)$: Number of medical talents required per 10000 population in year t

$r_4(t)$: A fraction of medical graduates who actually become medical doctors in year t

$r_5(t)$: A fraction of medical doctors who leave clinical practice in year t

$r_6(t)$: A fraction of newly enrolled students who actually register for classes in year t

$r_7(t)$: A fraction of medical students who actually graduate in year t

$r_8(t)$: The adjustment factor of student enrollments in year t (due to the influence of outside factors)

Since there three state/block variables, there are obviously three flow equations, each of which can simply be developed using the quantity-balance principle:

First, the quantity balance of the entire population (a driving factor):

The change in population during year t

= Number of births during year t – Number of natural deaths in year t

Mathematically, this is represented by:

$$\frac{dx_1}{dt} = x_1(t)r_1(t) - x_1(t)r_2(t) \quad (1)$$

Second, the quantity balance of the medical doctor population (demand):

The change of medical doctor population during year t

= Number of medical graduates who actually become medical doctors in year t

– Number of medical doctors who leave clinical practice during year t

– Number of natural deaths of medical doctors in year t

Mathematically, this is represented by:

$$\frac{dx_2}{dt} = x_3(t)r_4(t)r_7(t) - x_2(t)r_2(t) - x_2(t)r_5(t) \quad (2)$$

Finally, the quantity balance of the medical student population (supply):

The change of medical student population during year t

= Number of students actually enrolled in year $t - t_1$ (assumed to stay in colleges until graduation (where t_1 is the typical number of years required to graduate)

– Number of medical students actually graduates in year t who leave clinical practice during year t

– Number of natural deaths of medical doctors in year t

And the number of students actually enrolled in year $t - t_1$

= (Predicted number of medical doctors required to meet the target level of medical doctors in year $t - t_1$

– Number of medical doctors in year $t - t_1$)

* A fraction of newly enrolled students who actually register for classes in year t

* Adjustment factor due to outside influences.

$$= \max\left(0, \left(x_1(t-t_1)r_3(t-t_1) - x_2(t-t_1)\right)r_6(t-t_1)r_8(t-t_1)\right)$$

(The max function is to ensure the quantity is never negative.)

Mathematically, this flow equation is represented by:

$$\frac{dx_3}{dt} = \max\{0, \left(x_1(t-t_1)r_3(t-t_1) - x_2(t-t_1)\right)r_6(t-t_1)r_8(t-t_1)\} - x_3(t)r_7(t) - x_3(t)r_2(t) \quad (3)$$

Model Output

Since we will use the model to predict the supply and demand of medical talents, we will be tracking the values of $x_2(t)$, $x_3(t)$ and the ratio $x_2(t)/x_1(t)$ throughout the planning horizon. The last quantity tracked represents the actual number of medical doctors per 1000 people in the population, which can match the desired target level. Policy adjustments can then be made to ensure that the system produce the desired target level of medical doctors per 1000 capita.

Model Summary

The dynamic model of supply and demand of medical talents can be summarized as follows:

System Equations:

$$\frac{dx_1}{dt} = x_1(t)r_1(t) - x_1(t)r_2(t)$$

$$\frac{dx_2}{dt} = x_3(t)r_4(t)r_7(t) - x_2(t)r_2(t) - x_2(t)r_5(t)$$

$$\frac{dx_3}{dt} = \max\{0, \left(x_1(t-t_1)r_3(t-t_1) - x_2(t-t_1)\right)r_6(t-t_1)r_8(t-t_1)\} - x_3(t)r_7(t) - x_3(t)r_2(t)$$

System Output: $x_2(t)$, $x_3(t)$ and the ratio $x_2(t)/x_1(t)$.

Model Calibration

The model is calibrated to predict the supply and demand of medical talents in Jiangsu Province, China. Accordingly, data from Jiangsu Provincial Statistics Bureau (2010-2014) and Editorial Committee of Jiangsu Health Yearbook (2010-2014) were used to estimate all parameters $r_i(t)$ except $r_3(t)$, in the form of table functions as shown in the **Appendix** (see **Tables 4-11**). For the table function representing the target number of medical doctors per 1000 capita, data from OECD 34 counties were used resulting in the table function for $r_3(t)$ as seen in the appendix (see **Appendix**, **Table 6**).

Model Validation

We have argued earlier that the systems dynamics model (1)-(3) above is quite appropriate to represent a complex system to study the interplay between supply and demand of medical talents. To run simulation using the model, it would be easy to do so using a dynamic simulation algorithm using MATLAB or Simulink. The table functions representing the values of all parameters $r_i(t)$ can be easily treated as piecewise linear functions, which is handle through an interpolation function. Simulation runs can also be easily made using any system dynamic software system such as STELLA or VENSIM. In this paper, we used VENSIM.

To validate the model, we again use historical data on the number of medical doctors and the number of medical education students from Jiangsu Provincial Statistics Bureau (2010-2014) and Editorial Committee of Jiangsu Health Yearbook (2010-2014) to perform model validation. The simulation results are shown in **Figure 5**, **Figure 6** and **Figure 7**.

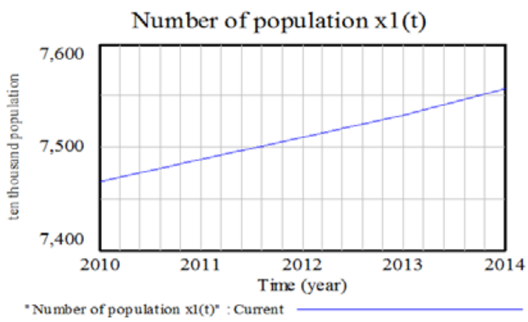

Figure 5. Simulation results of the number of population

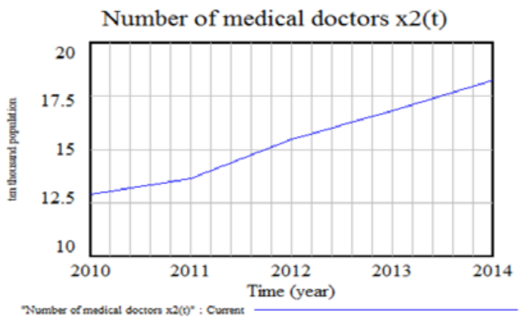

Figure 6. Simulation results of the number of medical doctors

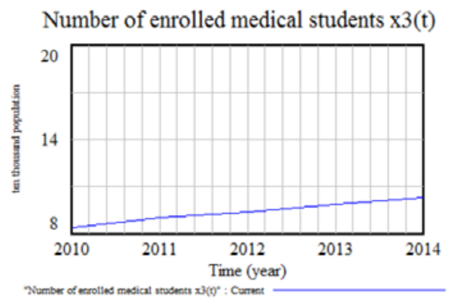

Figure 7. Simulation results of the number of medical student's enrollment in school

Tables 1, **2** and **3** compare the simulated data with the actual data (from Jiangsu Province from 2010 to 2014) with percentage error computed using formula as shown in equation (4).

$$\%error = \frac{|x - x_1|}{x} \times 100\% \quad (4)$$

It can be seen that in most cases the % error lies below 0.5%. There are 2 out 15 cases where the %error is around 1% with 2.2% being the maximum. These results clearly indicate the validity of the model.

RESULTS

Predicting Future Values of all Parameters:

The time series values of $r_1(t)$, $r_2(t)$, $r_3(t)$, $r_4(t)$, $r_5(t)$, $r_6(t)$, $r_7(t)$, $r_8(t)$ from 2010 to 2014 can be obtained from Jiangsu Provincial Statistics Bureau (2010-2014) and Editorial Committee of Jiangsu Health Yearbook (2010-2014). If we would like to predict near-future values of these parameters, we can easily do so using an appropriate forecasting method. For example, if we use a curve-fitting routine from MATLAB, the least squares fit results with the corresponding predictive equation are shown in **Figure 8** to **Figure 15**. These equations can of course be used to predict the values of the parameters in the near future.

Table 1. Error analysis of simulation results and actual values of the number of population

Time (Year)	2010	2011	2012	2013	2014
Simulation Value (x_1)	7466.59	7488.62	7509.36	7531.51	7556.14
Simulation Value (x_1)	7466.59	7514.25	7553.48	7616.84	7684.69
% error	0	0.34%	0.58%	1.12%	1.67%

Table 2. Error analysis of simulation results and actual values of the number of medical doctors

Time (Year)	2010	2011	2012	2013	2014
Simulation Value (x_2)	12.9	13.61	15.45	16.82	18.22
Simulation Value (x_2)	12.9	13.47	15.80	16.97	17.86
% error	0	1.03%	2.2%	0.88%	2.01%

Table 3. Error analysis of simulation results and actual values of the number of medical student's enrollment

Time (Year)	2010	2011	2012	2013	2014
Simulation Value (x_3)	8.3855	9.0047	9.3965	9.9131	10.31
Simulation Value (x_3)	8.3855	8.9847	9.3519	9.9031	10.2863
% error	0	0.22%	0.47%	0.1%	0.23%

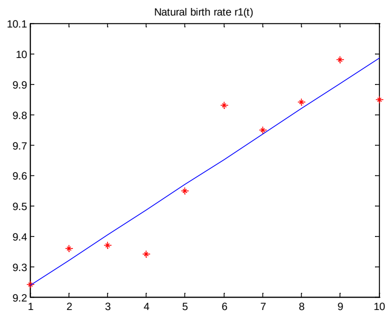

Figure 8. $r_1(t)$ vs. t
$r_1(t) = 0.083t + 9.1547$

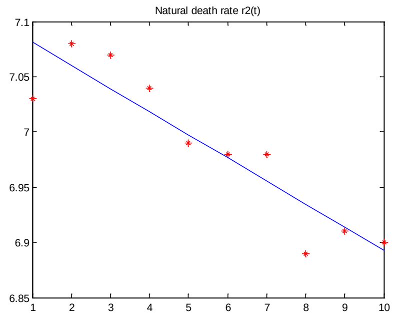

Figure 9. $r_2(t)$ vs. t
$r_2(t) = -0.0209t + 7.102$

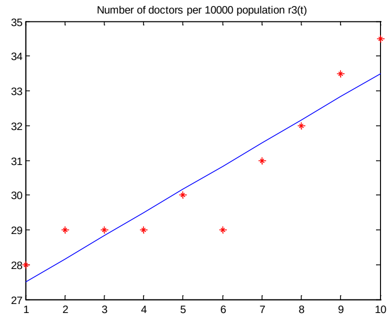

Figure 10. $r_3(t)$ vs. t
$r_3(t) = 0.6667t + 26.8333$

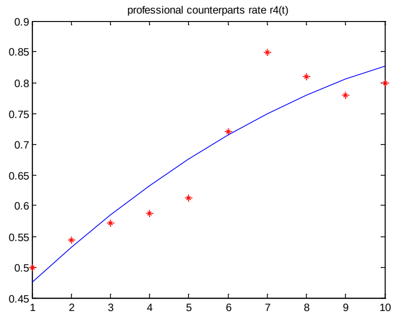

Figure 11. $r_4(t)$ vs. t
$r_4(t) = 0.0022t^2 + 0.631t + 0.4149$

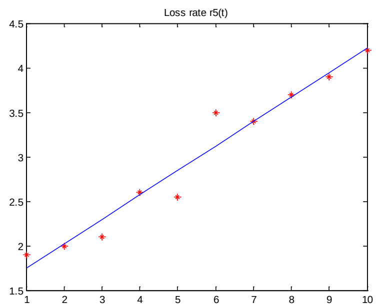

Figure 12. $r_5(t)$ vs. t
$r_5(t) = 0.2748t + 1.4733$

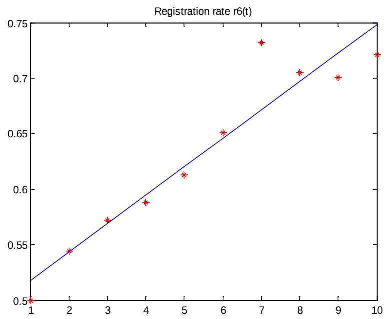

Figure 13. $r_6(t)$ vs. t
$r_6(t) = 0.0256t + 0.492$

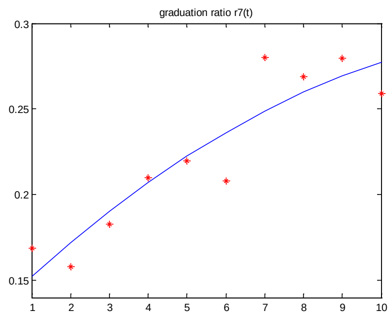

Figure 14. $r_7(t)$ vs. t
$r_7(t) = 0.0007t^2 + 0.0218t + 0.1313$

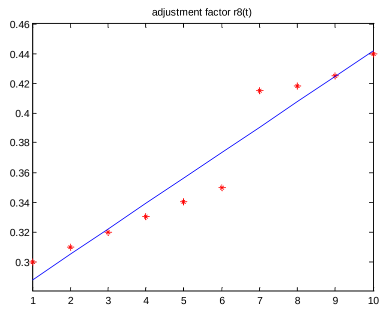

Figure 15. $r_8(t)$ vs. t
$r_8(t) = 0.0339t + 0.1515$

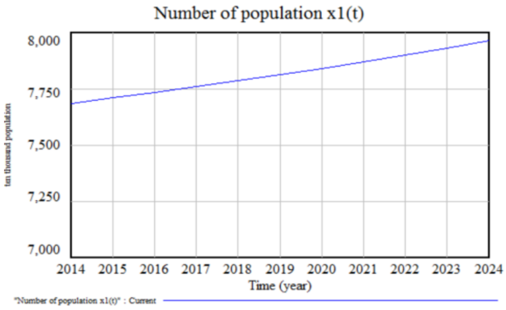

Figure 16. Forecasted number of population

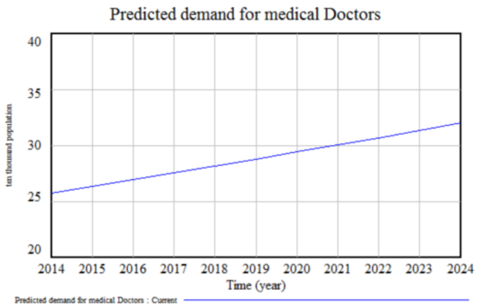

Figure 17. Forecasted demand for medical talents

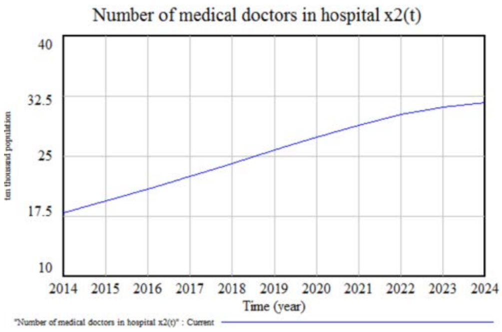

Figure 18. Forecasted number of medical doctors available

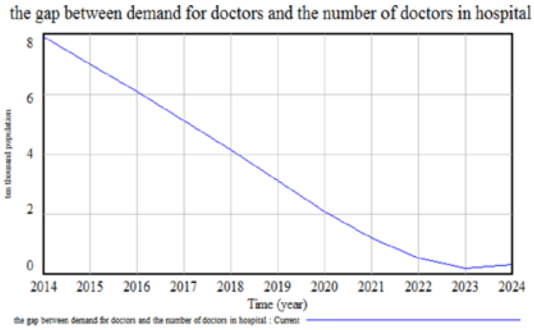

Figure 19. Forecasted number of the gap

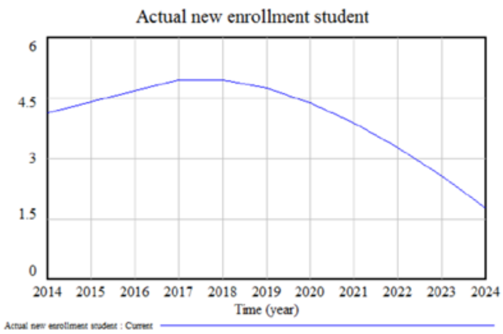

Figure 20. Forecasted number of actual new enrollments

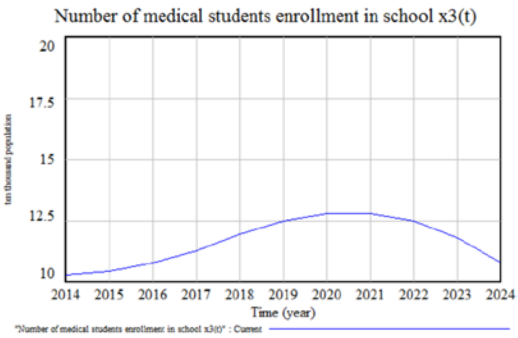

Figure 21. Forecasted medical students enrolled

Predicting Supply and Demand of Medical Education Talents

The calibrated model was run from 2014 to 2024. The forecasted numbers of population, of demand for medical doctors, of medical doctors, of potential medical students, of actual new student enrollments, and of medical student's enrollment in school are shown in Figure 16 to Figure 21.

Figure 16 shows that the number of population in Jiangsu Province is likely to increase slowly reaching 79.6 million in 2024, from just 76.8 million in 2014. This represent an increase of about 3 million in 10 years or about 3.6% per year.

Figure 17 shows that the demand for medical talents in Jiangsu Province increases from about 257,400 in 2014 to about 319,800 in 2024. This represents about 24% increase in 10 years or about 2.4% annually. This is to maintain the target level (according to OECD 34 counties average) of about 4 medical doctors per 1000 people.

Figure 18 shows that the number of medical talents increases from 178,600 in 2014 to a high of about 316,500 in 2024, which practically matches the demand in 2024 of about 319,800. This represents 77.2% increase in ten years or about 7.7% annually, which is quite high. At this level of medical doctors available, the average level of OECD 34 counties is practically achieved.

Figure 19 shows that the number of the gap between demand for doctors and the actual doctors in hospital decreases continually reaching zero in 2024 and then continue to increase. This is due to the fact that the number of medical doctors increases rapidly during the 10 years planning horizon closing the gap with the demand level until the gap is practically closed in 2024. Hence, at that time, the supply for medical doctors through medical education is no longer needed but the new demand may be needed.

Figure 20 shows that the number of actual new student enrollments increases initially until 2022 (8 years later) and begins downward trends thereafter. The change in the number of actual new student enrollments student follow the pattern of change in the number of supply of potential medical students, although it lags behind 4 years (assuming that the colleges are 4-year colleges).

Finally, Figure 21 shows that the number of medical student's enrollments in medical colleges increase initially reaching the peak of 128,000 in 2018 (this peak is 4 years ahead of the peak of the actual new student enrollments in Figure 20 (in the 4-year colleges). It then decreases rapidly thereafter until it reaches the level of about 107,000 in 2024.

DISCUSSION

In the model validation phase, the maximum error of the model was 2.2%, which is relatively low. However, this error may increase in the process of future prediction, mainly due to the following 3 reasons:

(1) The model did not take into account the collapse of the system caused by major changes in policy and abnormal circumstances. However, the changes of Chinese population planning policy will undoubtedly affect the natural population growth rate; the improvement of medical environment will affect the loss rate, registration rate and graduation ratio.

(2) The model did not take into account the time-lag of each variable (for example, the transformation from medical graduates to officially registered medical doctors usually requires some time period for residency training, etc.)

(3) In the model, the only sources of medical doctors considered were graduates of medical colleges and universities. Potentially, there may be other sources of medical talents such as web-based training institutions and migration of medical talents from outside the system under consideration, etc.. With the development of information technology, the distance education of web-based training will become more and more popular. Therefore, in order to improve the accuracy of the prediction, the coefficients $r_1(t)$~$r_8(t)$ should be adjusted as function of time to appropriately account for these potential changes. Not only this will help improve prediction accuracy, it should also help flexibility of the model and widen the range of application.

CONCLUSIONS

The people of China are experiencing tremendous economic growth and are reaping the benefits, both economically and socially, of their precipitously new-found wealth. The Jiangsu provincial government has proposed to do what it can to support the new upmarket life style and social well-being of its 76 million citizens. However, healthcare services and medical education in China have not kept pace with its great economic growth. Healthcare performance indicators such as the number of medical talents per 1000 capita, ratio of doctors to nurses, educational years of medical personnel, quality and quantity of medical education to train medical personnel and so on, have not been on par with the standards of even moderately developed countries. Based on current data, there is still quite a large gap between these indexes in China and the desired target levels. Moreover, because of

China's recently relaxed family planning policy in 2016 and the increased aging population, there are even greater needs to improve medical/healthcare services both in quality and quantity. The demand for larger pools of medical talents on the one hand and for bigger and more productive medical education system on the other is more pronounced than ever. Therefore, medical colleges and universities must adjust their education systems and policies to produce high quality medical talents in sufficient quantity to meet the rapidly growing needs of the evolving Chinese population. Consequently, the system and structure of medical education need to be adjusted. The corresponding policies and management system need to be reformed, and the medical environment improved.

In order to assist policy makers to make the necessary reforms and adjustments, the model of supply and demand of medical doctors developed in this paper should be very useful. It focuses expressly on the demand and supply of medical doctors. It includes all key factors that have significant impacts on the demand and supply. It emphasizes on essential interactions including core dynamics and feedback loops that highlight emerging properties of the system. The model can make accurate forecast of the demand for medical talents and the number of medical graduates who actually enter the medical practice. Accordingly, the model allows scenario/policy analysis to be performed to produce insights that would be useful in formulating national strategies and policies on national healthcare system and medical education.

The model can also be used as a reference for the prediction and training of registered nurses.

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APPENDIX

Table 4. The table function for $r_1(t)$

Time (Year)	2010	2011	2012	2013	2014
Value $r_1(t)$	0.00983	0.00975	0.00984	0.00998	0.00985

Table 5. The table function for $r_2(t)$

Time (Year)	2010	2011	2012	2013	2014
Value $r_2(t)$	0.00688	0.00698	0.00689	0.00671	0.00702

Table 6. The table function for $r_3(t)$

Time (Year)	2010	2011	2012	2013	2014
Value $r_3(t)$	29	31	32	32.5	33

Table 7. The table function for $r_4(t)$

Time (Year)	2010	2011	2012	2013	2014
Value $r_4(t)$	0.82	0.90	0.81	0.78	0.8

Table 8. The table function for $r_5(t)$

Time (Year)	2010	2011	2012	2013	2014
Value $r_5(t)$	0.035	0.034	0.037	0.039	0.042

Table 9. The table function for $r_6(t)$

Time (Year)	2010	2011	2012	2013	2014
Value $r_6(t)$	0.79	0.82	0.85	0.87	0.85

Table 10. The table function for $r_7(t)$

Time (Year)	2010	2011	2012	2013	2014
Value $r_7(t)$	0.2079	0.2803	0.2691	0.2798	0.2891

Table 11. The table function for $r_8(t)$

Time (Year)	2010	2011	2012	2013	2014
Value $r_8(t)$	0.35	0.415	0.418	0.425	0.49