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Equity Assessment of the Distribution of CT and MRI Scanners in China: A Panel Data Analysis

--Manuscript Draft--

Manuscript Number:	IJEH-D-18-00062R1
Full Title:	Equity Assessment of the Distribution of CT and MRI Scanners in China: A Panel Data Analysis
Article Type:	Research
Abstract:	Background: Distribution equity assessment of Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) scanners is an important dimension of health technology access. However, few study make necessary exploration on it in China. The study aims to reveal the distribution status of CT and MRI scanners and assess the distribution equity of them in China. Methods: Five provinces with 66 cities from China were selected as the sample sites. Descriptive analysis was used for the absolute number and number per million population of CT and MRI scanners in the study sites. Pearson Correlation Analysis and Fixed Regression Model was used to examine the health service factors that were associated with the allocation of CT and MRI scanners. Gini coefficient and Concentration index were used to evaluate the distribution equity of CT and MRI scanners. Results: The general level of absolute number and number per million population of CT and MRI scanners in 5 provinces was lower than that of OECD countries, but the annual growth rates were relatively higher from 2005 or 2006 to 2013. Population, GDP, number of hospitals, number of health professionals, number of hospital beds, number of outpatient visits, number of inpatient visits all had a positive correlation with the allocation number of CT and MRI scanners. While the number of health professionals and number of inpatient visits had a much closer correlation than other variables. All the Gini coefficients of CT and MRI had decreased overall. The concentration indices of CT and MRI were all positive and no more than 0.30. Conclusions: There are still large gaps in the number of CT and MRI scanners per million population between China with Organization for Economic Co-operation and Development (OECD) countries although the growth rate was much higher in China. The distribution equity of CT and MRI scanners in China is relatively good from 2005 or 2006 to 2013, and the overall distribution equity of CT and MRI scanners has been improving during the period. But attention shall be paid to the area with large economic disparities.
Response to Reviewers:	Reviewer #1: The paper is interesting, covers an important topic. I feel there are several major concerns that need to be addressed. 1. The reader is not told how the GINI coefficient was calculated, was population size and GDP taken into account? Answer: I have added the formulas and illustration of GINI coefficient and concentration index in the manuscript. 2. No account is taken of need for MRI/CT, health status varies between regions and thus need for these machines Answer: I agree that the need for MRI/CT should be took into consideration in the allocation of them. However it is very complicated to determine the indictors of need for MRI/CT. So we use the correlation analysis and panel regression analysis to help investigate the influencing factors which will help combine the allocation with the need in our follow-up research. 3. While OECD countries may have more machine, it is unclear if there is a health benefit from a certain number of machines, what is the optimum number of machines per population? Having more is not necessarily a good thing. In fact there are real harms from having more than are needed. Japan has >100 CT per million, may well be causing much harm through needless investingations, with false positive results, and resources diverted from more important needs. Answer: There is no unanimously approved optimum number of machines per population so far. The common method to evaluate the allocation level of the high technology medical equipment is to compare with OECD countries in many researches. It may not be the best method, but it can reflect the gap from the

perspective of the population. As the reviewer have said above, it will be more precise to assess the allocation level combing with the need.
4. The use of the term 'health systems' for the factors analysed is not correct. At best the authors use 'health service indicators'. If the authors wish to claim they are assessing the health system factors, they would need to place these within some definition of health system, the WHO building blocks etc. The first paragraph of the discussion section needs to be rewritten, I am unable to discern what most sentences mean in that paragraph, an important one. Line 49 on the 1st page of the discussion ascribes the differences to developing versus developed, there are multiple other factors at play, historical approach to care, balance between primary and higher level care etc. The last page of the discussion, line 13, notes that the findings may extend the existing investigations, and gives lessons, but does not state what lessons those are. The writing could be clearer, and small errors removed, e.g. OECD is spelt out in the conclusion of the abstract, but mentioned in the results. If the English is not perfect, make sure there are no careless errors. The claim on the 4th paragraph of the introduction that this research is urgent is somewhat overstated. I am concerned about the focus on number of machines, it is also important how many scan are done, what the quality of those are, the ratio between mri and CT, the distribution within each province. For example, a person living in the rural are of a province which has the highest density of machines, but all the scans are in the capital city may have less access than someone living in a province with fewer machines, but spread into different hospitals. My comment here is about how valid the indicator is? What is known about the indicator? I don't see enough theory about the strength and weaknesses of the indicator. Methods line 54, 'low socioeconomic development' does this mean low compared to what? Who was the questionnaire addressed to (line 5 above the statistical analysis)Please explain how the AGR is calculated (table 2)
Answer: I have adopted “health service indicators” in the paper. The first paragraph of the discussion section have been rewritten, and some adjustment has also been made according to other advice. As to the utilization of CT and MRI scanners, it will be discussed in our another study later.
Reviewer #2: The study aims to reveal the distribution status of CT and MRI scanners and assess the distribution equity of them in China, however, CT and MRI scanners are now common medical equipment in China, the distribution equity assessment can't reveal and solve practical problems. The study could analysis the utilization situation, which may provide much scientific policy recommendations for the government.
Answer: Though CT and MRI scanners are wildly used in China now, new technology of CT and MRI have been emerging continuously, and the government still takes the management of the allocation of CT and MRI scanners seriously according to the latest government files. The reasonable allocation is still an important and difficult issue which concerns the health right of citizens. As to the utilization of CT and MRI scanners, it will be discussed in our another study later.
Review 3 summary:
The study uses a 8-year survey panel data of 66 cities out of 5 provinces to understand the CT and MRI distributions in China. The sample frame, sample size, and the investigators’ efforts across years deserve praise. However, the writing of the manuscript is weak and it needs major revision.
My comments/questions/suggestions are enumerated below.
1.The manuscript is poorly written in terms of academic English writing. Singular and plural forms are the most common mistakes. For example, it should be “few studies” at line 4 page 3, “…and Fixed Regression Model were used” at line 17, page 3. There are also a lot of phrases that are not used appropriately. For example, “access to health technologies” is more appropriate than “health technology access” at line 2, page 3, “the general level of” is redundant at line 23 page 3. These errors appear in the manuscript frequently and harm the readability of this manuscript. I would strongly recommend the authors use academic language editing service for this manuscript.
Answer: Apparent error of academic English writing have been corrected according to the comments.
2.In the introduction, I would suggest the author to add more background on CT & MRI use in China, and the rationale of investigating CT & MRI use in China between paragraph 1 and 2. It seems that there is a gap between paragraph 1 and 2. The literature review at the paragraph 2 is too weak to intrigue the readers’ interest on CT and MRI use in China.
Answer: The paper focus on the allocation of CT and MRI scanners in China. The use of them is not involved in this paper. So I think it is not essential to add the contents.

	3.I would suggest the authors to delete the Pearson correlation analysis in "statistical analysis", "results", "discussion" and delete your table 4. Correlation analysis is uninformative when conducted before multivariate analysis since these suspicious significant correlations could disappear when a third variable is added into your regression model. In this sense, Pearson correlation neither contributes to variable selection in your regression, nor is the simple correlation informative to the readers. Answer: The part on the correlation analysis has been removed from the paper. 4.Please use fixed effect regression/model instead of "fixed regression" across the manuscript. Answer: I have corrected the words and fixed effect model was used across the paper. 5.Please specify your fixed effects regression in formulas and illustrate the variables and error terms. Answer: The formulas have been specified in the part of methods. 6.Hausman test is used to test the null hypothesis of random effects model (RE) is preferred against the fixed effects (FE) model. However, you should use Breusch-Pagan test to test the null hypothesis of pooled regression before you test RE against FE. Answer: I have added the P values of F test which showed that fixed effects (FE) model was better than pooled regression in table 4 and table 5. 7.You used OLS FE in this study. The classic OLS relies on the normality assumption to have best linear unbiased estimator. However, the first two lines of your table 3 suggest that 'N of CTs" and "N of MRIs" are highly right skewed. The two variables are left censored at 0, while the max values are way more than the means plus three standard deviations, which indicate that they are highly right skewed. Therefore, OLS FE in this case may not an appropriate model for your data. I would suggest you use log transformation on the two outcomes. It would be more feasible to transform y+1 since the min of "N of MRI" is 0, which is mathematically erroneous when you take the log of 0. Answer: Log transformation was used to conduct the regression analysis and the result has been updated in table 4 and table 5. 8. Please add a column of median on table 3 since most of the variables are right skewed. Answer: I have added the median in table 3. 9.I suggest you add the percent of old people (>=65 years old) in the sample cities in your regression model. This is an important variable that could predict the number of CTs and MRIs in sample cities. Answer: The percent of old people was not included in our investigation and could not be obtained from the open channels. I will take it into consideration in our further research. 10.Using one "macro" variable at a time is a way to reduce multicollinearity. However, your excluded 4 variables in each model, and only 3 independent variables may not be sufficient to explain your dependent variables, the R squares look fair though. I suggest you add one more regression in your table 5 and table 6, which is using principle component analysis to cluster your suspected highly correlated independent variables and then then run the regression using the principle components. Answer: I have tried to involve more variables in my model, but multicollinearity did not allow me. I have also tried principle component analysis, and only one principle component could be extracted. And the main objective of the regression analysis is not to construct the best model, but to explore the relationship between the variables and the number of CT and MRI scanners. 11.There are a lot of concentration indexes and the most famous one is the Herfindahl-Hirschman index. I suggest specify your formulas for calculating Gini coefficients and concentration index, and explain the variables you use. Your entire manuscript is based on the two measures. Without clear explanation of how you construct them, the evidence of this paper is not reliable. Answer: The formulas of Gini coefficients and concentration index have been specified in the part of method. 12.Report the actual P values instead of just p<0.05 for the Hausman test in table 5 and 6. Answer: All the P values of Hausman test and F test showed infinitely close to zero, so I could not report the actual P values. 13.When reporting the R square in study, we normally report adjusted R square instead of original R square. However in your study, R squares should equal the adjusted R squares across model 1 to model 5, but it does no harm to point that out.

	Answer: STATA was used to conduct the FE model and only R square was present in the results after the code was executed. 14.R square is not informative enough for comparing different models. I would suggest you add AIC and BIC in companion with adjusted R square to show the model fits. Answer: STATA was used to conduct the FE model and only R square was present in the results after the code was executed. 15.The discussion part is simply rewording the results part and do not show adequate critical thinking on this topic. In this study, low CT and MRI rates per million people compared with OECD countries indicate worse access to healthcare. The high increasing rates of CTs and MRIs in China seem to be exhilarating and beneficial to Chinese patients. However, some concerns may arise: does the fast-increasing trend imply "medical arm race"? Is it possible that physicians may induce medical demand since they balance the cost of purchasing CTs and MRIs? Could the increasing CT and MRI rates lead to much higher medical expenditure for patients? What does relevant research say about these concerns? These are aspects where critical and insightful thinking should be displayed in the discussion part. Answer: I have added some contents in the section of discussion. Owing to the limited data, some topics could not be discussed for now. I will try to answer them in my further study. 16.What are illustrations of this study to the world, especially those fast-developing countries? How can they apply the result of this study? Answer: I have added some sentences in the last paragraph. Reviewer #4: It is a good topic to study the distribution of CT and MRI Scanners in China, which is closely related to the medical equity issues of China. To improve this research, I have some comments on this paper. 1. It is suggested to add maps to better show the distribution of CT and MRI Scanners in China. Answer: Only the data of 5 provinces were obtained in our study, so we cannot show the overall distribution of CT and MRI Scanners in China. Moreover the data is time-series which is hard to show in the maps. We will try to visualize the distribution of the HTME in China as soon as we obtain the data of the whole country. 2. In the introduction section, it is better to add the introduction of the Chinese healthcare system. For example, what is the level of China's medical equipments? is the equipment purchased by the government (central government, or local government, or hospitals)? Answer: The allocation level of CT and MRI scanners of China was present in paragraph 2. The purchase of CT or MRI scanners can be classified into several categories, including hospital-paid, government reimbursement, government-paid, donate and so on. Bur we didn't obtain the data on purchase, so the information cannot be added in this paper. 3. In the method section, it is suggested to introduce the collection of questionnaires. What is the main content of the questionnair? What is the response rate? Answer: I have added the detail information about the questionnaire in the 2nd paragraph of the section of method. 4. The author have analyzed the degree of concentration and Gini coefficient at the provincial level. It is better to add the analysis at the city level. Are these devices concentrated in large hospitals(san jia hospital)? Is the distribution of CT and MRI consistent with the distribution of some diseases? Answer: The quantity of CT and MRI scanners at the county or district level was not investigated in our research, so I cannot add the analysis at the city level. It is same to hospital and disease analysis, owing to the lack of relevant data. 5. It is better to add the analysis of the usage frequency of those equipments. Answer: As to the utilization of CT and MRI scanners, it will be discussed in our another study later.

Equity Assessment of the Distribution of CT and MRI Scanners in China: A Panel Data Analysis

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Abstract

Background: Distribution equity assessment of Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) scanners is an important dimension of access to health technology. However, few study make necessary exploration on it in China. The study aims to reveal the distribution status of CT and MRI scanners and assess the distribution equity of them in China.

Methods: Five provinces with 66 cities from China were selected as the sample sites. Descriptive analysis was used for the absolute number and number per million population of CT and MRI scanners in the study sites. Pearson Correlation Analysis and fixed effect model was used to examine the health service factors that were associated with the allocation of CT and MRI scanners. Gini coefficient and Concentration index were used to evaluate the distribution equity of CT and MRI scanners.

Results: The absolute number and number per million population of CT and MRI scanners in 5 provinces was lower than that of OECD countries, but the annual growth rates were relatively higher from 2005 or 2006 to 2013. Population, GDP, number of hospitals, number of health professionals, number of hospital beds, number of outpatient visits, number of inpatient visits all had a positive correlation with the allocation number of CT and MRI scanners. While the number of health professionals and number of inpatient visits had a much closer correlation than other variables. All the Gini coefficients of CT and MRI had decreased overall. The concentration indices of CT and MRI were all positive and no more than 0.30.

Conclusions: There are still large gaps in the number of CT and MRI scanners per million population between China with Organization for Economic Co-operation and Development (OECD) countries although the growth rate was much higher in China. The distribution equity of CT and MRI scanners in China is relatively good from 2005 or 2006 to 2013, and the overall distribution equity of CT and MRI scanners has been improving during the period. But attention shall be paid to the area with large economic disparities.

Keywords: High technology medical equipment, Equity, Gini coefficient, Concentration index

Introduction

CT and MRI scanners are now common medical equipment in China and play a highly important role in the diagnosis of diseases. CT and MRI scanners belong to the category of Type-Ⅱ High Technology Medical Equipment (HTME), and they are managed by the national and provincial health department according to the *Management Methods on Allocation and Utilization of High Technology Medical Equipment* issued in 2005 by the National Health and Family Planning Commission (NHFPC; formerly the Ministry of Health)[1]. HTME refers to either the medical equipment included in the management list of Health Department under the State Council or the equipment that are not included in the list but priced at above 5 million Chinese yuan (CNY) and allocated at provincial level hospitals for the first time. The Certificate of Need (CON) policy, established as the list went into effect, aims to improve "appropriate allocation and efficient use of medical equipment" through regional health planning and quota control. NHFPC controls the total amount of HTME in China, and provincial health departments formulate allocation plans under the quota set by NHFPC[2]. NHFPC is responsible for CON licensure of Type-Ⅰ HTME, while provincial health departments are responsible for that of Type-Ⅱ HTME. Hospitals must apply for CON before purchasing HTME.

Some studies found that, although the numbers of CT and MRI scanners per million population in China were lower than the medians in OECD countries, the growth rate was higher in China than in most of the OECD countries[2, 3]. The numbers of CT and MRI scanners at secondary hospitals and tertiary hospitals of China were 12,888 and 6,762 respectively in 2015 according to the statistics of the Chinese Medical Doctor Association (CMDA). With the widespread use and increasing number of CT and MRI scanners in China, macro research on them has become urgently needed to provide evidence for the improvement of the management policy. However, few studies could provide an overview of CT and MRI scanners in China. There are three gaps identified in the macro research on CT and MRI scanners in China.

First, there is little research evidence showing the distribution trend of CT and MRI scanners in China. Some research has tried to show the distribution of CT and MRI scanners in China to some extent[4-8]. Owing to the few provinces or short period, usually we cannot obtain a clear overview.

Second, there are few research studies exploring the correlation between health service indicators and distribution of CT and MRI scanners in China. Studies on the determinants of the distribution of HTME were conducted by researchers from countries other than China, but few have been done in China. While some studies analyzed the influence of population and gross domestic product (GDP) on the distribution of CT and MRI scanners, few studies analyzed the influence of health service indicators [2, 9].

Third, there is little research revealing the changing trend of distribution equity of CT and MRI scanners in China. Previous studies focus more on the equity of them in a certain region or a short period. The improvement or setback of distribution equity cannot be recognized clearly in China, especially after the implementation of CON policy [10-15].

This study tries to describe the allocation of CT and MRI scanners in China after the implementation of the CON policy and conduct preliminary investigation of the influence of health service indicators on the distribution of CT and MRI scanners in China. Since the OECD consists of developing countries and developed countries and may represent the average level of the allocation number of CT and MRI scanners around the world, the comparison of the numbers of CT and MRI per million population is made between China and OECD. We will also evaluate equity as an important aspect of the appropriateness of CT and MRI scanner distribution as well as the changing trend of distribution equity after the implementation of the CON policy. We hope that this study will fill the gaps in the current evidence base to some extent.

Methods

Sample and data collection

Sixty-six cities in five provinces in China were selected as the sample sites in our study, including Zhejiang, Guangdong, Hunan, Shanxi, and Shaanxi Provinces. Zhejiang and Guangdong are in East China and represent provinces with advanced socioeconomic development in China. Hunan and Shanxi are in the central region of China and represent medium socioeconomic development in China. Shaanxi is in West China and represent low socioeconomic development in China.

Data were collected from the provincial health department in each of the five provinces. The demographic and socioeconomic data of 66 cities within the five provinces were obtained from the Statistical Yearbook of each province from 2005 to 2013. The numbers of CT and MRI scanners from 2005 to 2013 and other health system data including the number of hospitals, number of beds, number of health professionals, number of inpatient visits, number of outpatient visits from 2009 to 2013 were gathered through a questionnaire addressed to the provincial health department. 5 questionnaires filled out by the 5 provincial health departments were collected via mail. Owing to data loss, the numbers of CT and MRI scanners of Shanxi in 2005 and Shaanxi in 2005, 2007, 2008 were not included in the analysis.

Statistical analysis

Numbers and growth rates of CT and MRI scanners

Descriptive analysis was used for the absolute numbers and numbers per million population of CT and MRI scanners in the study sites and the OECD countries. The annual growth rates (AGRs) of the two types of medical equipment were also calculated from 2005 or 2006 to 2013. The formula of AGR is as follows：

$$\mathrm{AGR} = \sqrt[n]{\frac{B}{A}} - 1$$

B is the quantity of CT or MRI scanners in 2013, A is the quantity of CT or MRI scanners in 2005 or 2006, n represents the number of year.

Influencing effect of health service indicators on the distribution of CT and MRI scanners

Fixed effect model (FE model) was conducted to deepen our analysis based on the Hausman test and F test [16]. The dependent variable is the absolute numbers of CT and MRI scanners, and the independent variables consist of the population, GDP, number of hospitals, number of health professionals, number of hospital beds, number of outpatient visits, and number of inpatient visits of a given city [9, 17-19]. Since there is a strong self-correlation among all health service indicators, they were included in the model separately with socioeconomic variables. Fixed effect model in this study could be expressed in the following equation where Y_{it} referred to the number of CT or MRI scanners, $X_{k,it}$ to other covariates in the model, a_i to the intercept and μ_{it} to error term. Log transformation was used to cope with the abnormal distribution of the number of CT or MRI scanners. $Y_{it}+1$ was transformed for the number of CT or MRI scanners since the min value of that is 0. STATA 13.0 was used to conduct the analysis.

$$\ln Y_{it} = \ln \beta_1 X_{1,\ \mathrm{it}} + \ln \beta_2 X_{2,\ \mathrm{it}} + \cdots + \ln \beta_k X_{k,\ \mathrm{it}} + a_i + \mu_{it}$$

$$\ln(Y_{it} + 1) = \ln \beta_1 X_{1,\ \mathrm{it}} + \ln \beta_2 X_{2,\ \mathrm{it}} + \cdots + \ln \beta_k X_{k,\ \mathrm{it}} + a_i + \mu_{it}$$

Equity assessment on the distribution of CT and MRI scanners

Gini coefficient and Concentration index were used to evaluate the equity of the distribution of CT and MRI scanners. Gini coefficient was primarily developed and used in economics, but now it has also been widely recognized in public health and epidemiology. Gini coefficient takes on the value from 0 to 1. According to the conception of Gini coefficient, the bigger the value, the more inequitable the distribution. A Gini coefficient that is smaller than 0.2 indicates a very low inequity level, and one that is bigger than 0.4 means a high inequity level[20, 21]. The following formula was employed to calculate the Gini coefficient:

$$\mathrm{G} = \sum_{i=1}^{n} P_i Y_i + 2\sum_{i=1}^{n-1} P_i(1 - V_i) - 1$$

P_i is the cumulative proportion of the population in each group; Y_i is the cumulative proportion of the health resources in each group; $V_i = Y_1 + Y_2 + \ldots\ldots Y_i$; i is the fractional rank in terms of the number of CT and MRI scanners from the lowest number to the highest number.

Concentration index was introduced to measure the inequity of health and medical services in different socioeconomic conditions by the World Bank. It could quantify the level of inequity of the distribution of health resources relevant to the economy. Its value ranges from -1 to 1. The bigger the absolute value, the more inequitable the distribution. 0 means absolute equity. The Concentration index could also reflect the direction of the distribution of the resource. A positive value indicates that resources gather in the richer area, while a negative value means that resources gather in the poorer area[22-24]. The following formula was employed to calculate the concentration index:

$$S = \frac{1}{2}\sum_{i=0}^{n=1}(Y_i + Y_{i+1})\,(X_{i+1} - X_i)$$

Y_i is the cumulative proportion of CT and MRI scanners, X_i is the cumulative proportion of population, and i is the fractional rank according to per capita GDP beginning with the lowest; CI represents the concentration index.

STATA13.0 with the DASP package was used to calculate the Gini coefficient and Concentration index. DASP, which stands for Distributive Analysis Stata Package, is mainly designed to assist those researchers and policy analysts who are interested in conducting distributive analysis with Stata[25].

Results

Numbers of CT and MRI scanners in the study sites

Table 1 showed the distribution and average annual growth rate of CT and MRI scanners in the five provinces from 2005 or 2006 to 2013. The numbers of CT and MRI scanners had both been increasing during the period, and the number of MRI scanners grew faster than that of CT scanners. Overall, the numbers of CT and MRI scanners in Zhejiang, Guangdong, and Shaanxi were larger than those in Hunan and Shanxi, so were the average annual growth rates which were 12.01%, 11.69%, and 11.78% respectively versus 3.11% and 6.96% respectively for CT scanners, and 15.40%, 16.03%, 22.94% respectively versus 11.61% and 11.50% respectively for MRI scanners.

Table 1 Numbers of CT and MRI scanners in 5 provinces

	Province	2005	2006	2007	2008	2009	2010	2011	2012	2013	AGR
CT	Zhejiang	138	178	207	230	266	302	343	378	429	12.01%
	Guangdong	239	265	287	384	445	553	615	675	722	11.69%
	Hunan	299	334	342	344	352	359	369	386	406	3.11%
	Shanxi		163	168	172	176	185	230	240	261	6.96%

	Shaanxi		194			321	350	376	398	423	11.78%
MRI	Zhejiang	37	47	60	71	74	86	106	125	155	15.40%
	Guangdong	66	71	83	101	106	153	199	249	292	16.03%
	Hunan	48	58	66	70	78	87	98	111	144	11.61%
	Shanxi		35	39	39	42	46	61	70	75	11.50%
	Shaanxi		49			81	107	135	167	208	22.94%

Table 2 showed the changing trend of the numbers of CT and MRI scanners per million population in the five provinces from 2005 or 2006 to 2013. While the numbers had been increasing across all five provinces, the numbers in Zhejiang, Guangzhou, and Shaanxi were higher than those in Hunan and Shanxi during the period. The annual growth rates were 10.93%, 10.07%, and 11.50% versus 2.53% and 5.85% for CT scanners, and 14.29%, 14.35%, and 22.64% versus 10.99% and 10.35% for MRI scanners. The numbers of CT and MRI scanners per million population in Shaanxi grew the fastest.

The descriptive statistics for the distribution of CT and MRI scanners in OECD countries were also presented in Table 2. Up to 2013, the mean and median number of CT scanners per million population in OECD countries were 22.94 and 17.71 respectively, larger than those of the five provinces in China. It was same for MRI scanners, which were 13.61 and 11.32 in OECD countries.

Table 2 Numbers of CT and MRI scanner per million population in 5 provinces and OECD countries

	Province	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**AGR**
CT	Zhejiang	2.76	3.51	4.02	4.41	5.04	5.54	6.28	6.90	7.80	10.93%
	Guangdong	2.60	2.81	2.97	3.88	4.39	5.30	5.85	6.37	6.78	10.07%
	Hunan	4.73	5.27	5.38	5.39	5.49	5.46	5.59	5.81	6.07	2.53%
	Shanxi		4.83	4.95	5.04	5.14	5.18	6.40	6.65	7.19	5.85%
	Shaanxi		5.24			8.61	9.37	10.05	10.60	11.24	11.50%
MRI	Zhejiang	0.74	0.93	1.16	1.36	1.40	1.58	1.94	2.28	2.82	14.29%

	Guangdong	0.72	0.75	0.86	1.02	1.05	1.47	1.89	2.35	2.74	14.35%
	Hunan	0.76	0.91	1.04	1.10	1.22	1.32	1.49	1.67	2.15	10.99%
	Shanxi		1.04	1.15	1.14	1.23	1.29	1.70	1.94	2.07	10.35%
	Shaanxi		1.32			2.17	2.86	3.61	4.45	5.53	22.64%
Descriptive statistics of OECD Countries											
CT	Mean	17.02	18.42	18.85	21.92	20.39	20.68	23.72	21.91	22.94	3.03%
	Median	11.96	13.09	14.09	14.61	14.99	15.70	16.15	16.79	17.71	4.00%
	Min	3.36	3.40	3.84	4.02	4.14	4.69	4.52	5.10	5.32	4.70%
	Max	51.54	56.72	36.95	96.97	39.14	43.07	101.25	50.51	53.68	0.41%
MRI	Mean	9.22	8.97	9.87	11.34	11.14	12.20	12.68	12.46	13.61	3.97%
	Median	5.40	5.71	7.19	8.57	8.68	9.27	9.55	9.83	11.32	7.68%
	Min	1.33	1.38	1.67	1.62	1.85	1.90	1.95	2.17	2.07	4.52%
	Max	40.14	26.58	25.93	42.96	25.15	31.52	46.86	34.44	35.48	-1.23%

Influencing effect of health service indicators on the distribution of CT and MRI scanners

Table 3 showed the description statistics of the main variables of 66 cities in the five provinces from 2009 to 2013. Owing to the different levels of socioeconomic development in the eastern, central, and western regions, the values of the variables varied greatly.

Table 3 Description statistics of main variables

Variable	Median	Mean	SD	Min	Max
N of CT	23.00	28.54	22.09	6.00	167.00
N of MRI	6.00	9.12	9.46	0.00	84.00
Population (10,000)	385.71	434.36	220.57	83.31	1292.68
GDP (billion CNY)	111.82	190.35	230.31	15.44	1542.01
N of hospitals (100)	57.00	71.04	52.94	12.00	281.00
N of Health professionals (100)	124.53	164.79	142.14	21.04	819.22

N of Beds (100)	108.45	138.29	113.09	19.76	648.64
N of outpatient visits (10,000)	371.87	837.89	1435.81	4.41	8735.53
N of inpatient visits (10,000)	28.24	37.13	31.88	4.41	205.42

SD: standard deviation; N: number; Min: minimum; GDP: gross domestic product

The results of the panel regression analysis were present in table 4 and 5. Five different health service indicators are included in five regression models respectively combining with population and GDP for both CT and MRI scanners. We found that when the number of health professionals was brought into the model, it had the largest power to predict the distribution of CT and MRI scanners according to the value of R^2, then the number of beds, number of hospitals, number of inpatient visits and number of outpatient visits.

Table 4 Results of panel regression analysis for CT scanners distribution

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Population	0.95^{*}	0.87^{*}	0.88^{*}	0.90^{*}	0.86^{*}
GDP	0.49^{**}	0.32^{**}	0.45^{**}	0.41^{**}	0.41^{**}
Hospitals	0.11				
Health professionals		0.43^{**}			
Beds			0.13		
Outpatient visits				0.17^{**}	
Inpatient visits					0.14^{*}
Constant	-6.47^{**}	-8.34^{**}	-6.49^{**}	-6.10^{**}	-5.40^{*}
Model	FE Model	FE Model	FE Model	FE Model	FE Model
F test	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$
Hausman test	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$
R^2	0.37	0.43	0.38	0.29	0.38

$^{*}p<0.05$; $^{**}p<0.01$

Table 5 Results of panel regression analysis for MRI scanners distribution

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
Population	-0.30	-0.57	-0.67	-0.51	-0.91

GDP	1.01 **	0.70 **	0.75**	0.81 **	1.04 **
Hospitals	0.55 **				
Professionals		0.97**			
Beds			0.72 **		
Outpatient visits				0.54**	
Inpatient visits					0.005**
Constant	-5.62	-8.75 *	-5.95	-3.67	-0.13
Model	FE Model	FE Model	FE Model	FE Model	FE Model
F test	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$
Hausman test	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$
R^2	0.33	0.43	0.37	0.12	0.22

*$p<0.05$; **$p<0.01$

Equity assessment across cities within each of the study sites

Gini coefficient

Table 6 showed the Gini coefficients of CT and MRI scanners in the five provinces from 2005 or 2006 to 2013. Gini coefficients of CT scanners decreased from 0.225 to 0.153 in Zhejiang during 2005-2013, from 0.336 to 0.226 in Guangdong during 2005-2013, from 0.143 to 0.119 in Hunan during 2005-2013, from 0.181 to 0.176 in Shanxi during 2006-2013, from 0.131 to 0.090 in Shaanxi during 2006-2013, and from 0.238 to 0.220 across all five provinces during 2006-2013. Though fluctuated, the overall Gini coefficient decreased. The Gini coefficients of MRI scanners were larger than those of CT in the same year. Gini coefficients of MRI scanners in Zhejiang decreased from 0.336 to 0.155 during 2005-2013, from 0.402 to 0.313 in Guangdong during 2005-2013, from 0.276 to 0.175 in Hunan during 2005-2013, from 0.298 to 0.262 in Shanxi during 2006-2013, from 0.287 to 0.091 in Shaanxi during 2006-2013, and from 0.341 to 0.305 across all five provinces during 2006-2013. All Gini coefficients showed a downward trend overall. Figures 1 and 2 clearly showed the changing trend of Gini coefficients of CT and MRI scanners.

Table 6 Gini coefficients of CT and MRI scanners in 5 provinces

	Province	2005	2006	2007	2008	2009	2010	2011	2012	2013
CT	Zhejiang	0.225	0.156	0.125	0.136	0.146	0.124	0.144	0.148	0.153
	Guangdong	0.336	0.318	0.317	0.254	0.217	0.223	0.222	0.233	0.226
	Hunan	0.143	0.117	0.115	0.117	0.111	0.106	0.105	0.106	0.119
	Shanxi		0.181	0.172	0.183	0.175	0.170	0.150	0.156	0.176
	Shaanxi		0.131			0.094	0.089	0.092	0.090	0.090
	Total		0.238			0.221	0.208	0.208	0.213	0.220
MRI	Zhejiang	0.336	0.304	0.284	0.197	0.173	0.202	0.170	0.162	0.155
	Guangdong	0.402	0.375	0.353	0.332	0.309	0.307	0.279	0.317	0.313
	Hunan	0.276	0.292	0.305	0.313	0.282	0.245	0.231	0.227	0.175
	Shanxi		0.298	0.278	0.278	0.319	0.251	0.220	0.267	0.262
	Shaanxi		0.287			0.202	0.128	0.096	0.106	0.091
	Total		0.341			0.311	0.293	0.282	0.306	0.305

Concentration index

Table 7 showed the Concentration indices of CT and MRI scanners in the five provinces from 2005 or 2006 to 2013. All Concentration indices were positive. The Concentration indices of CT scanners in Zhejiang, Guangdong, Shanxi, and Shaanxi showed a downward trend, changing from 0.126 to 0.121 during 2005-2013, from 0.238 to 0.174 during 2005-2013, from 0.120 to 0.066 during 2006-2013, and from 0.112 to 0.073 during 2006-2013 respectively. However, the Concentration index of CT scanners in Hunan and the overall index of the five provinces increased from 0.019 to 0.045 during 2005-2013 and from 0.050 to 0.109 during 2006-2013 respectively. The Concentration indices of MRI scanners in Hunan and Shanxi showed a downward trend, changing from 0.172 to 0.037 during 2005-2013 and from 0.218 to 0.177 during 2006-2013 respectively. However, the indices of Zhejiang, Guangdong, and Shaanxi and the overall index of the five provinces increased from 0.076 to 0.088 during 2005-2013, from 0.170 to 0.109 during 2005-2013, from 0.025 to 0.081 during

2006-2013, and from 0.108 to 0.130 during 2006-2013 respectively. Figures 3 and 4 visualized the aforementioned results.

Table 7 Concentration index of CT and MRI scanners in 5 provinces

	Province	2005	2006	2007	2008	2009	2010	2011	2012	2013
CT	Zhejiang	0.126	0.093	0.079	0.090	0.113	0.095	0.119	0.121	0.121
	Guangdong	0.238	0.238	0.236	0.164	0.157	0.157	0.165	0.182	0.174
	Hunan	0.019	0.026	0.037	0.041	0.028	0.021	0.025	0.035	0.045
	Shanxi		0.120	0.122	0.117	0.122	0.095	0.063	0.056	0.066
	Shaanxi		0.112			0.079	0.070	0.070	0.077	0.073
	Total		0.050			0.054	0.067	0.083	0.099	0.109
MRI	Zhejiang	0.076	0.139	0.071	0.102	0.108	0.110	0.088	0.124	0.088
	Guangdong	0.170	0.228	0.237	0.218	0.200	0.221	0.229	0.259	0.254
	Hunan	0.172	0.162	0.140	0.114	0.036	0.021	0.002	0.015	0.037
	Shanxi		0.218	0.193	0.182	0.227	0.191	0.125	0.148	0.177
	Shaanxi		0.025			0.119	0.080	0.072	0.087	0.081
	Total		0.108			0.098	0.098	0.093	0.126	0.130

Discussion

The allocation level of CT and MRI scanners in Zhejiang, Guangdong which are from the eastern regions of China is the highest among the 5 provinces. The results may attribute to the different level of socioeconomic in different regions of China which has been recognized be some studies. The result of panel regression analysis in this research also validated the influencing effect of GDP on the distribution of CT and MRI scanners. The influence of economic factors may also lead to concentration in the big cities of some provinces. For example, the percentage of CT scanners in Xian which is the capital of Shannxi province reached 39.1% of the total in 2013, while the percentage of MRI scanners in Guangzhou, Shenzhen and Foshan reached 52.4% of the 21 cities in Guangdong province. Attention should be paid to the phenomenon to avoid over-concentration of HTME and allocation plan of HTME formulated by the health department should ensure the accessibility of poor area.

Comparing with OECD countries, the five provinces had much lower mean and median number of CT scanners per million population. The numbers of CT scanners per million population in Korea and Japan, China's neighboring countries, are much higher than that in China, e.g., Japan has achieved over 100 CT scanners per million population. The numbers of MRI scanners per million population in the five provinces were more than 50% lower than the mean and median in OECD countries. OECD countries also gained more MRI scanners per million population than the five provinces did in 2013. These findings indicate that the availability of CT and MRI scanners in China is far behind the average level of availability in OECD countries. However, China's annual growth rate is much higher than the average annual growth rate in OECD countries. Considering the economic development and health demands of China, the increasement of the number of CT and MRI scanners will continue and the gap will be narrowed. However, the number of CT and MRI scanners in OECD countries is just a reference for China and we should not just focus on the quantity, the reasonable allocation level should be determined by combing with the real demand.

The correlation analysis shows that GDP, population, the number of hospitals, number of health professionals, number of hospital beds, number of outpatient visits, and number of inpatient visits, all have a positive correlation with the distribution of CT and MRI scanners. While we find out that the number of health professionals and the number of beds have a larger impact on the distribution than other variables do in the panel regression models. The influencing effect of health service indicators on the distribution of HTME has been confirmed in some studies[9, 26, 27]. The comparison among health service indicators in our research may extend existing investigations and provide policy recommendations for the allocation plan of HTME in China. The determinants of the distribution of HTME still need further exploration and health service indicators should be involved in the future research. The number of health professionals and the number of inpatient visits should be emphasized in the formulation of the allocation plan and a formula consist of these indicators could be derived to determine the quantity of CT and MRI scanners.

In terms of the equity assessment of CT and MRI scanners in the five provinces, Gini coefficient and Concentration index show that the distribution of CT and MRI scanners is fairly equitable and that the distribution of CT scanners is more equitable than that of MRI scanners. CT scanners are used more widely than MRI scanners, since the lower price of CT scanners make them more affordable for most hospitals, and MRI scanners are more likely to concentrate in cities with good economic condition. The equity of the distribution of CT and MRI scanners has improved after the implementation of the CON policy. The allocation plan for Type-Ⅱ HTME that is issued by the provincial health department has taken economic factors and health needs into consideration to some extent. The Gini coefficients of CT scanners reveal that Shaanxi has the most equitable distribution of CT scanners, followed by Hunan, Zhejiang, Shanxi, and Guangdong. Up to 2013, the distribution of CT scanners in Shaanxi, Hunan, Zhejiang, Shanxi had been in absolute equity, while that of Guangdong has been in relative equity. Shaanxi also has the most equitable distribution of MRI scanners, followed by Zhejiang, Hunan, Shanxi, and Guangdong. Up to 2013, the distribution of MRI scanners in Shaanxi, Hunan, and Zhejiang had been in absolute equity, while that of Shanxi and Guangdong had been in relative equity. The highly differential levels of socioeconomic development among cities in Guangdong may explain the low equity.

The concentration indices of CT scanners in the five provinces are all positive but no more than 0.25 and have all decreased during the period. It indicates that CT scanners used to gather in cities in good economic conditions, but the situation has improved. The concentration indices of MRI scanners are also all positive and no more than 0.30. The indices in Hunan and Shanxi have decreased, while the rest has increased. It indicates that the distribution of MRI scanners that is based on economy is not so equitable as that of CT scanners, and MRI scanners also tend to gather in cities in good economic conditions. Meanwhile, the situation has become even worse in some provinces. The influence of economic factor accords with the regression analysis above, and the results are consistent with the findings of previous studies[13, 14].

Limitations

As the lack of details of CT and MRI scanners in the five provinces, the distribution trends and distribution equity of different row of CT scanners and different tesla of MRI scanners were not analyzed in this study. Besides, only seven variables were included in the panel regression analysis, we were not able to explore more variables relevant to the distribution of CT and MRI scanners. The contribution factors of the distribution inequity were not explored, either. It means that we cannot provide many suggestions to improve the distribution equity.

Conclusions

According to the analysis above, we conclude that there are still large gaps in the distribution of CT and MRI scanners between China and OECD countries. Combing with the demand, reasonable growth of the quantity of them should continue. Besides GDP and population, the health service indicators, especially the number of health professionals and number of beds should also be emphasized in the allocation plan of CT and MRI scanners. Future studies should include more factors in the analysis to inform allocation management. The distribution equity of CT and MRI scanners in the five provinces is relatively good. However, areas with large socioeconomic disparities need to receive more policy attention to ensure the equity of the distribution of CT and MRI scanners. The quantity of HTME in poor or remote areas should be guaranteed in the allocation plan. Same macroscopic interventions should be adopted to ensure the distribution equity of HTME and the allocation quantity of HTME should take the health service indicators into consideration which could be applied to other developing countries.

Abbreviations

CT: Computed Tomography; MRI: Magnetic Resonance Imaging; OECD: Organization for Economic Co-operation and Development; HTME: High Technology Medical Equipment; CON : Certificate of Need; MoH :Ministry of Health; CMDA: Chinese Medical Doctor Association; AGR: annual growth rate; FE model: fixed effect model; DASP: Distributive Analysis Stata Package;

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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Availability of data and materials

Data was collected from Statistical Yearbook of 5 provinces from 2005 to 2013 and the database of OECD available from https://data.oecd.org/.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

YYC,LYH contributed to the conception and framework of the study. JSG and YW contributed to the data analysis. LYH completed the final manuscript. All authors were involved in data collection.

Consent for publication

Not applicable.

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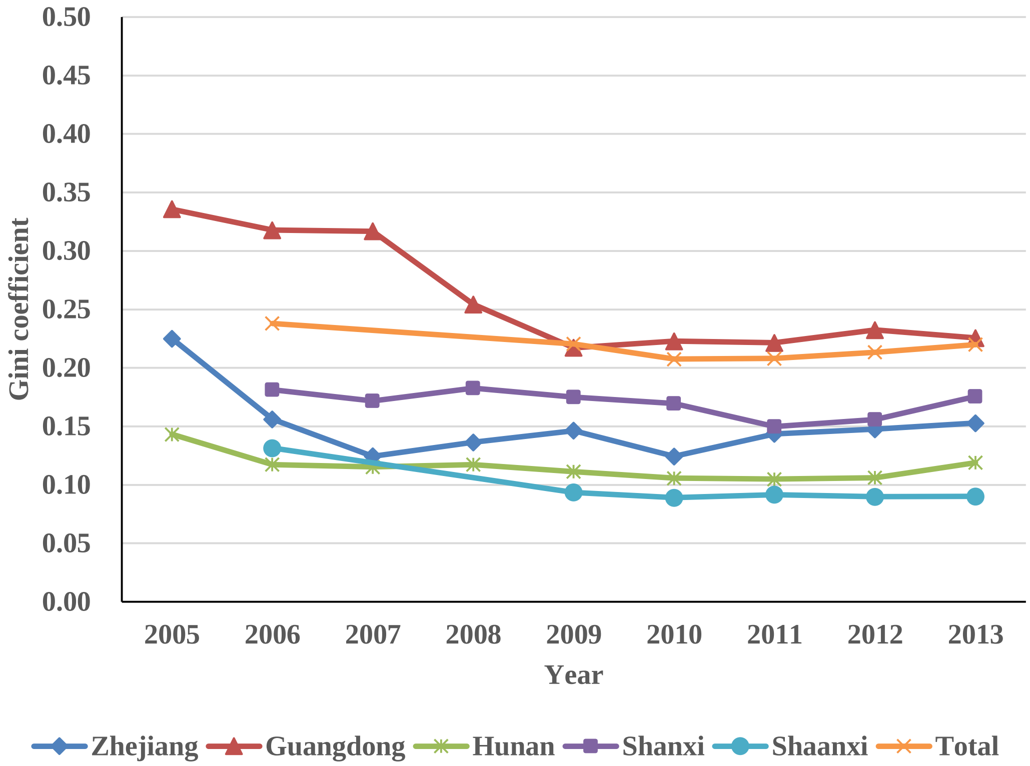

Figure 1 Gini coefficients of CT scanner in the five provinces

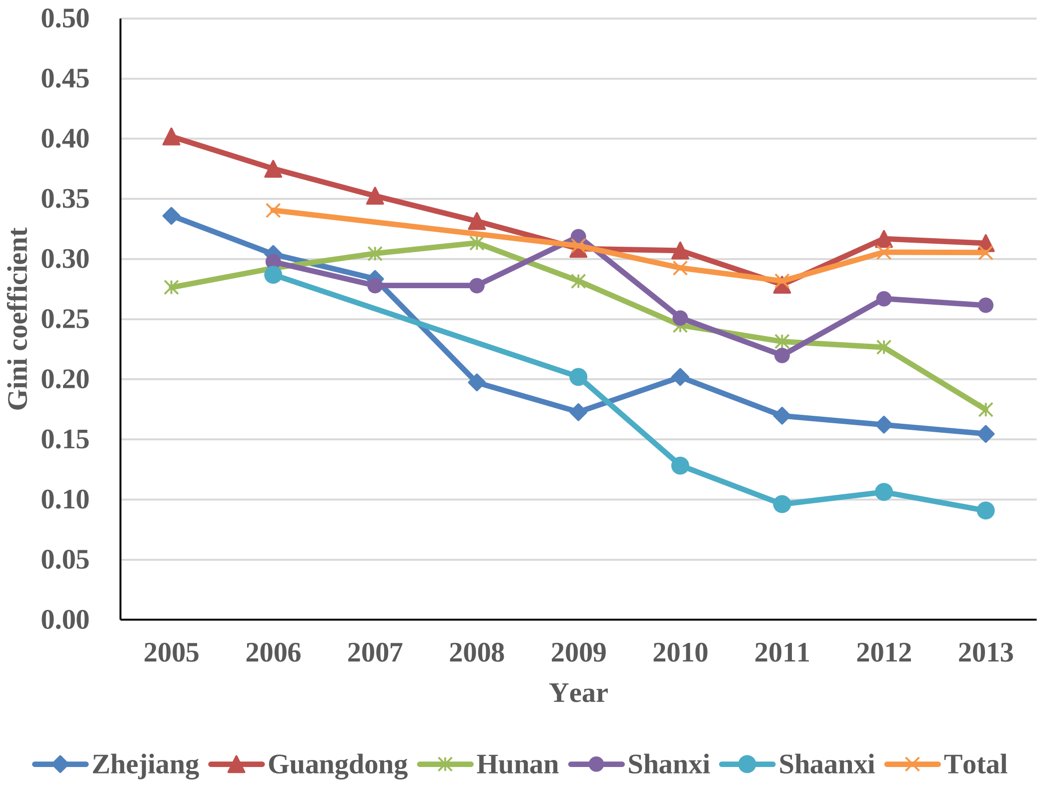

Figure 2 Gini coefficients of MRI scanners in the five provinces

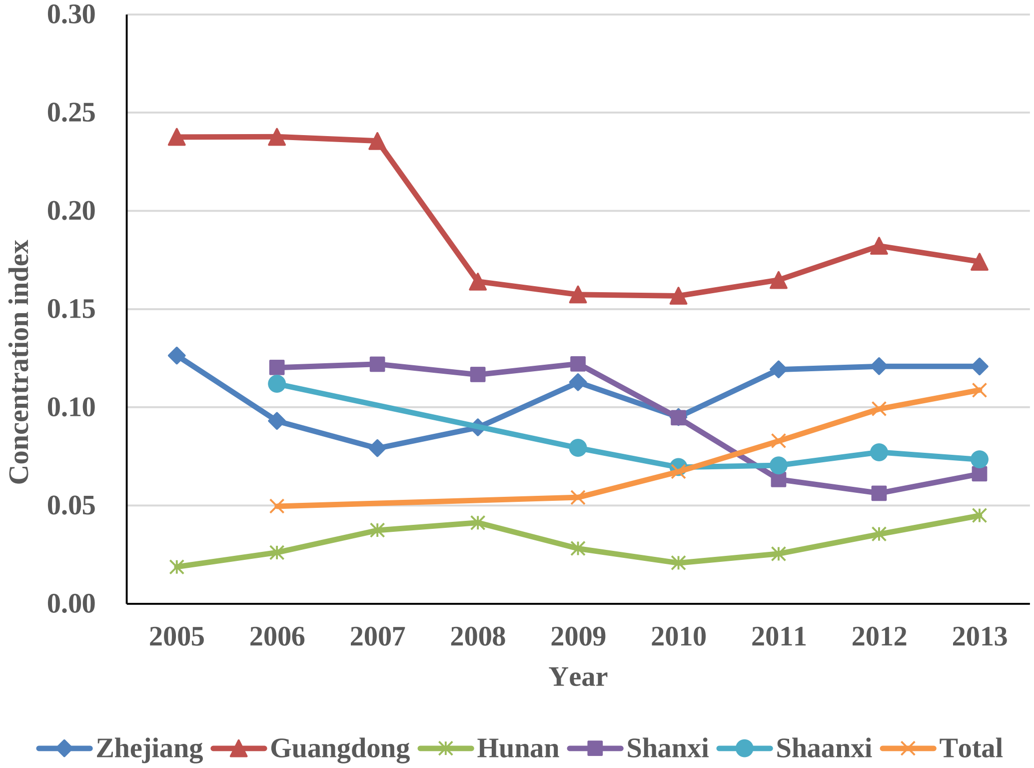

Figure 3 Concentration indices of CT scanners in the five provinces

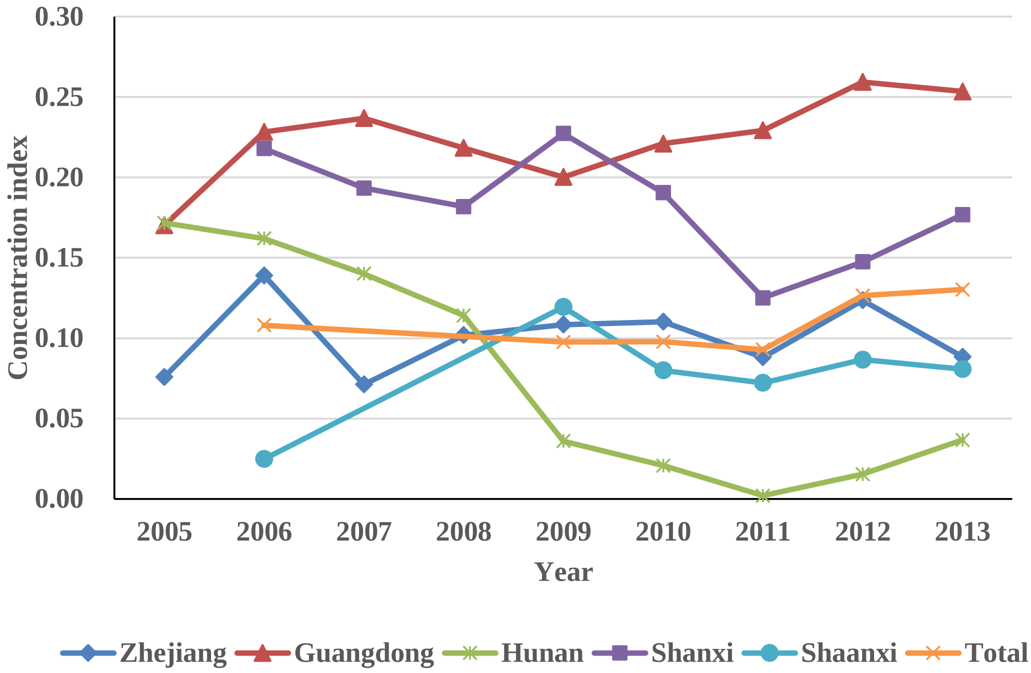

Figure 4 Concentration indices of MRI scanners in the five provinces

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