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ORIGINAL RESEARCH

Analysis of Relevant Factors Influencing the Development of Pharmacist Human Resources in China: Based on the Time Series Vector Auto-Regression Model

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Objective: To analyze and predict the dynamic influence trends and degrees caused by various factors that may affect the expansion of the hospital pharmacist team in China.

Methods: Time series data including the number of hospital visits in all hospitals in China, the total number of pharmacists, per capita health expenditure, and per capita GDP from 2002 to 2022 were collected at the national level. A vector autoregressive (VAR) model was constructed, and methods such as the Granger causality test, impulse response analysis, and variance decomposition were employed to explore the influence process and direction of various influencing factors on the number of pharmacists in China.

Results: The Augmented Dickey-Fuller (ADF) test indicates the first-order difference series of the time series is stationary ($P<0.05$). The model stability test shows the modulus of all specific root reciprocals falls within the unit circle, indicating model stability and credible results. The cointegration test reveals a cointegration relationship among the number of hospital visits, per capita health expenditure, per capita GDP, and the number of pharmacists ($P<0.05$). The Granger causality test indicates a unidirectional Granger causality relationship between the number of hospital visits, per capita health expenditure, and the number of pharmacists. The impulse response function indicates that the number of pharmacists shows an upward trend after being impacted by one unit of the number of hospital visits and per capita GDP, while the positive impact of per capita health expenditure on the number of pharmacists turns into a negative impact in the third stage. Variance decomposition shows that the contribution rate of the number of hospital visits to the number of pharmacists is 12%, the contribution rate of per capita health expenditure to the number of pharmacists is 57%, and the contribution rate of per capita GDP to the number of pharmacists is 80%.

Conclusion: The number of hospital visits, per capita health expenditures, and per capita GDP all positively contribute to the development of the pharmacist workforce. Per capita health expenditures lead to an increase in the number of pharmacists in the short term. Among the selected indicators, the primary drivers of pharmacist workforce development are per capita health expenditures and per capita GDP. Hospital visits have a relatively minor contribution to the growth in the number of pharmacists.

Keywords: number of pharmacists, vector autoregressive model, time series, Granger causality test

Introduction

On March 23, 2023 the Chinese government issued the "Opinions on Further Improving the Medical and Health Service System", proposing to improve the staffing standards of various professional public health institutions and enhance the level of drug supply guarantee and pharmaceutical services.[1] As the main body of drug supply and pharmaceutical service supply, the development of the number of hospital pharmacists is of great significance to the construction of China's medical team and the provision of pharmaceutical services. Hospital pharmacists are professional technical

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personnel in pharmacy who are engaged in hospital medical care and drug retail work, and directly interact with patients to provide pharmaceutical care services.[2] Statistics show that by the end of 2022, there were 530,000 pharmacists in China.[3] This was a 48.5% increase compared to 360,000 in 2002. During the same period, the number of doctors grew by 141%, and that of nurses by 319%. Overall, the number of pharmacists in China has been increasing year by year, but the growth rate is significantly lower than other healthcare professionals.[4] Additionally, the growing public demand for rational drug use does not align with the decreasing proportion of pharmacists. Therefore, it is urgent to deeply analyze the development of China's pharmacist workforce and identify factors affecting rational allocation of pharmacists.

The development of health human resources is influenced by multiple factors. Pang et al analyzed the correlation between the number of pharmacists in Japan and the United States from 1954 to 2004 and various economic indicators. The results indicated that factors influencing the scale of pharmacist human resources include: per capita GDP, per capita health expenditure, and per capita out-of-pocket payments.[5] Pascal Zurn emphasizes that economic, socio-demographic, cultural, and geographic factors - which contribute to the imbalance in the health workforce - play a crucial role in shaping and reshaping society. These factors have direct or indirect impacts on health workforce issues.[6] Per capita health expenditure refers to the ratio of the total amount of funds consumed by a society for medical and health services in a given period (usually one year) to the current total population.[7] It is an important indicator for measuring the level of health care provision in a country and can, to some extent, reflect the current demand for health care services.[8] Per capita GDP is the ratio of a country or region's gross domestic product (GDP) to its total population.[7] It effectively measures the living standards and development status of the people in that country or region, such as the level of development in areas like healthcare and social security.[9] The number of hospital visits in medical institutions is a key indicator for measuring patients' medical needs and reflecting the operational status and efficiency of these institutions.[10] It plays a significant role in optimizing the allocation of health resources, including human resources, and in regional health planning.[11] Hospital pharmacists supply and dispense medications within hospitals, and provide medication guidance and discharge education to patients. The number of hospital visits can reflect current societal demand for pharmacists.[12] Therefore, this study selects per capita GDP, per capita health expenditures, and the number of hospital visits as representative factors to explore their correlation with the number of pharmacists.

Current research on the Chinese pharmacist workforce mainly focuses on predicting workforce development through models, determining the rational ratio of pharmacists to healthcare professionals, and ensuring equitable pharmaceutical human resource allocation across regions.[13–16] However, studies exploring dynamic trends and correlations between relevant factors and pharmacist number development are relatively scarce in China. Moreover, the traditional models adopted have drawbacks such as being unable to fully explain the dynamic impact of the shock of a certain variable on other variables and involving too many subjective factors.[14,15] The VAR model is a model that uses non-structural methods to establish the relationships among various variables. It can effectively avoid the problem of variables being endogenous to each other and overcome the shortcomings of traditional models.[17] It is often used to predict interconnected time series systems and analyze the dynamic impacts of random disturbances on variable systems.[18] Therefore, it has been widely applied in research on healthcare expenditures and pharmaceutical economics.[19–21] This study collects data on the total number of hospital visits in Chinese hospitals, per capita health expenditures, per capita GDP, and the number of pharmacists nationwide from 2002 to 2022, constructing a time series VAR model. It uses Granger causality analysis, impulse response functions, and variance decomposition to explore the dynamic impact processes and magnitudes of these indicators on the development of the pharmacist workforce. This provides data support and theoretical foundations for the rational allocation of pharmacist human resources in China.

Methods

Data Sources

We collected data at the national level from three sources: the "China Health Statistics Yearbook" the "China Health Development Statistics Bulletin" and the "National Bureau of Statistics of China".[3,22,23] We extracted annual hospital visits, pharmacist numbers, per capita health expenditure and per capita GDP of all hospitals in China from 2002 to 2022 respectively. The number of pharmacists refers to the total number of individuals who have obtained hospital titles

nationwide each year. This includes pharmacy assistants, pharmacists, senior pharmacists, associate chief pharmacists, and chief pharmacists.[22] Per capita health expenditure is affected by inflation. The Consumer Price Index (CPI) translation is carried out to eliminate its impact (actual expenditure = nominal expenditure / price index, where price index = base period CPI / calculation period CPI, and the price index can be obtained from the statistical bureau).[24] Per capita GDP is a concept that excludes inflation and is not affected by it, so it does not need to be processed.[7] The term "hospital visits" refers to the total number of medical visits across the nation.[22] The number of all hospitals in China and the original data of each indicator can be found in Supplementary Table 1.

Data Processing

The per capita health expenditure is measured in "yuan", the number of hospital visits is measured in "hundred million visits", the per capita GDP is measured in "ten thousand yuan", and the number of pharmacists is measured in "ten thousand persons". To eliminate the influence of different dimensions among the indicators, each year's data is divided by the corresponding base year data (2002) to obtain the percentage values. The resulting per capita health expenditure is denoted as "NPCHC", the number of hospital visits is denoted as "NVZZL", the per capita GDP is denoted as "NPGDP", and the number of pharmacists is denoted as "NPZZL".

Model Building

Use the Eviews 12.0 software to construct the time series of the VAR model. The sequence NPZZL is constructed with NVZZL, NPCHC, and NPGDP to form models 1, 2, and 3 respectively, to explore the dynamic influence trends of NVZZL, NPCHC, and NPGDP on NPZZL. The stationarity of a time series is necessary for building a VAR model. If a time series is non-stationary, it can lead to spurious regression in the model, where variables appear to have a significant relationship, but this may be due to their common trends rather than a true statistical relationship. To check for stationarity, the Augmented Dickey-Fuller (ADF) test method is used to conduct unit root tests on each time series.[25] If the sequence is stationary (ADF, $P<0.05$), model it directly; If not (ADF, $P>0.05$), then under the premise of satisfying the same order single integer sequence, co-integration analysis is performed, and the co-integration test is determined by the trace statistic Trace. When there is a co-integration relationship between two sequences (none and at most 1, $P<0.05$), a VAR model can be constructed. The optimal lag period of the VAR model is determined comprehensively using AIC (Akaike Information Criterion), SC (Schwarz Criterion), and LR (Likelihood Ratio). Finally, the stability of the model is verified, and the Granger causality test, Impulse response function (IRF), and variance decomposition are analyzed. Since this article involves many methods in the field of econometrics, simple definitions and introductions of the relevant methods have been provided (Supplementary Information 1).

Results

The ADF test found that the original sequences NPZZL, NVZZL, NPCHC, and NPGDP cannot reject the null hypothesis of the existence of unit roots, so the original sequences are all non-stationary ($P=0.258$, $P=0.588$, $P=0.950$, and $P=0.711$). The first-order difference sequences reject the null hypothesis that the test sequence does not have a unit root and is a stationary sequence ($P=0.0200$, $P=0.0001$, $P=0.0108$, and $P=0.0028$). The premise of co-integration test is that the sequence to be tested is of the same order as a single integer, and the original sequences of NPZZL, NVZZL, NPCHC, and NPGDP are non-stationary. The first-order difference sequence is stationary and satisfies the same order as a single integer, which can be used for the co-integration test. The selection of the lag periods is highly sensitive to the results of co-integration tests. Different lag periods can lead to significant differences in the results of co-integration tests. Therefore, before establishing a VAR model and co-integration tests, it is necessary to determine the optimal number of lag periods. Based on the AIC, SC, and LR minimum principles, the optimal lag order for Model 1 was 2, while for Model 2 and Model 3, it was 1 (Supplementary Table 2). If there is a co-integration relationship between two non-stationary sequences, there may be a long-term relationship between them. The cointegration analysis reveals one cointegration relationship each between the NPZZL sequence and the NVZZL (none, $P = 0.0003$ and at most 1, $P = 0.4361$), NPCHC (none, $P = 0.0209$ and at most 1, $P = 0.4138$), and NPGDP (none, $P = 0.0120$ and at most 1, $P =$

0.3731) sequences. This indicates a long-term relationship between the development of pharmacist numbers and per capita health expenditure, per capita GDP, and hospital visits, rather than being due to a common growth trend.

The VAR model stability test (Figure 1) indicates that all the inverse AR roots lie within the unit circle, confirming the model's stability and high reliability. Therefore, further Granger causality tests, impulse response functions, and variance decomposition analysis can be performed on models 1, 2, and 3. The Granger causality can be used to test whether all lagged terms of a variable affect the current value of another variable or variables. The Granger causality test shows that, at a 5% significance level, the null hypothesis "NVZZL is not the Granger cause of NPZZL" is rejected (P=0.0141), but the null hypothesis "NPZZL is not the Granger cause of NVZZL" is not rejected (P=0.0968). This means that the number of hospital visits is the Granger cause of the number of pharmacists, but the number of pharmacists is not the Granger cause of the number of hospital visits. By the same reasoning, at a 5% significance level, there exists only unidirectional Granger causality between per capita health expenditure and the number of pharmacists, while no Granger causality is observed between per capita GDP and the number of pharmacists (Supplementary Table 3).

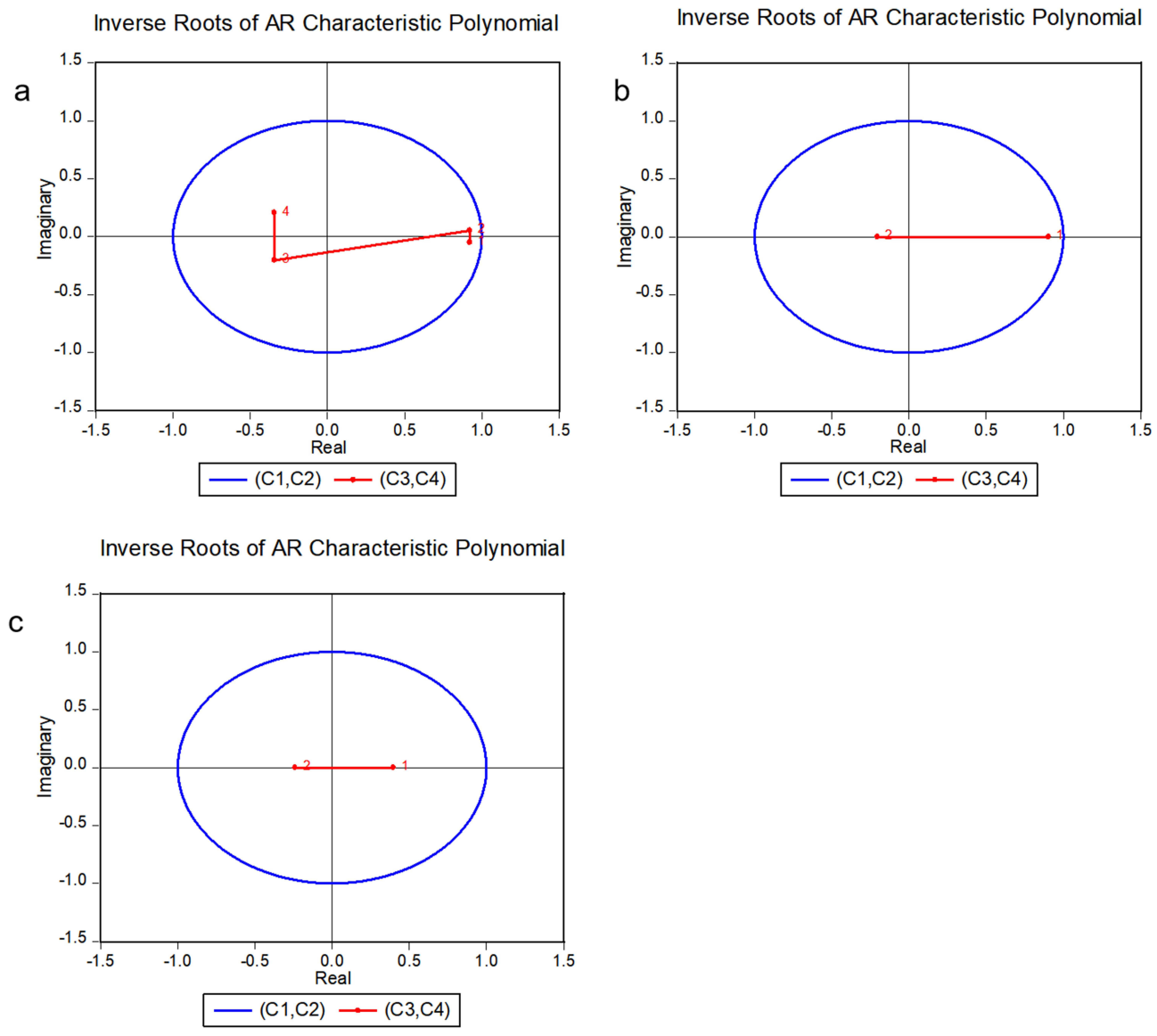

Figure 1 Stationarity test of VAR system. (**a**) Sequential NPZZL and NVZZL smoothness test results. (**b**). Sequence NPZZL and NPCHC smoothness test. (**c**) Sequential NPZZL and NPGDP smoothness tests. NPZZL represents the number of pharmacists, NVZZL represents the number of hospital visits, NPCHC represents per capita health expenditure, and NPGDP represents per capita GDP.

The IRF can be used to analyze the dynamic impact relationship between the variables of the VAR model, and the direction of the dynamic impact of a shock to one variable on itself and another variable can be observed.[26] As shown in Model 1, after a one-unit shock from NVZZL in the current period, NPZZL declines slightly in the first period but rises starting from the second period, peaking at 1.1 by the tenth period, and then stabilizing (Figure 2a). Thus, the number of hospital visits positively affects the number of pharmacists. In the long run, the number of pharmacists will rise with the increase in outpatient visits. As shown in Model 2, when there is a one-unit shock of NPCHC in the current period, NPZZL starts to rise gradually from the first period, reaching its peak of 1.5 in the second period, and then declines (Figure 2b). This decline slows down after the third period. Therefore, an increase in per capita health expenditures only leads to a short-term growth in the number of pharmacists. As shown in Model 3, after a one-unit shock to NPGDP, NPZZL rises slowly and peaks at 3.0 by the fifteenth period before stabilizing (Figure 2c). This indicates that an increase in per capita GDP promotes the growth of the pharmacist population.

The variance decomposition provides information about the relative degree to which each disturbance term factor affects each variable within the VAR model.[27] As shown in Model 1, as the number of periods increases, the portion of NPZZL variance explained by its own changes decreases, while the portion explained by NVZZL changes increases. By the fifteenth period, about 12% of NPZZL variance is explained by NVZZL changes, and 88% is explained by its own changes (Figure 3a). This implies that the degree to which the development of the number of pharmacists is influenced by internal factors is gradually decreasing, while the impact of the number of hospital visits on the number of pharmacists is gradually increasing. However, in the long term, the overall influence of the number of hospital visits on the number of pharmacists remains relatively small. Model 2 shows that the variance of NPZZL fluctuations initially drops sharply when explained by its own fluctuations, but slows down after the second period. Meanwhile, the portion of NPZZL variance explained by NPCHC fluctuations increases sharply at first, but the rate moderates later. By the fifteenth period, about 57% of NPZZL variance is explained by NPCHC fluctuations, while 43% is explained by its own fluctuations (Figure 3b). This indicates that the impact of per capita health costs on the number of pharmacists will gradually increase and surpass the impact of the number of pharmacists on itself. From Model 3, it's clear that the initial variance in NPZZL fluctuations is mostly influenced by its own fluctuations. But starting from the second period, the portion explained by its own fluctuations decreases gradually, while the portion explained by NPGDP fluctuations increases. By the fifteenth period, about 20% of the variance in NPZZL fluctuations is explained by its own fluctuations, and around 80% is explained by NPGDP fluctuations (Figure 3c). This shows that the positive effect of per capita GDP on the number of pharmacists is significant, and it's greater than the impact of the pharmacists' own actions.

Discussion

With an aging population and changes in the spectrum of diseases in China, the government and the public are getting increasingly concerned about health, and the demand for pharmacy services continues to increase commensurately. In this scenario, the number of pharmacists, as the main body of pharmacy services, should also be expanded accordingly.[28] China has issued the "Regulations on the Management of Pharmaceutical Affairs in Medical Institutions", which require pharmaceutical professionals to constitute no less than 8% of the total healthcare professionals in an institution, ensuring standardized medication management and patient safety.[29] However, Zhou Mingyue's research indicates that the staffing of pharmacists in China's healthcare institutions has consistently failed to meet the standard, with the proportion declining year by year and the gap to the 8% target widening progressively.[30] Studies by Chu Meijin and Lin Xiaodan further point out that the growth rate of pharmacists in China is significantly lower than that of other healthcare teams.[31,32] It is necessary to analyze the key driving factors behind the expansion of the hospital pharmacist workforce in China and their dynamic change mechanisms. Currently, research on the pharmacy workforce predominantly focuses on pharmacists' interventions in medication error information, the effectiveness of long-term blood pressure control, and the impact on patients' economic burden.[33–36] Additionally, there are cross-sectional studies on pharmacy labor, the influence of pharmacist staffing levels on prescription volumes, and research on predicting pharmacist staffing needs.[37,38] We have not yet found any research that macroscopically analyzes the correlation between health expenditure, GDP, hospital visits, and pharmacist development from a time series perspective in the long term. This study explores the

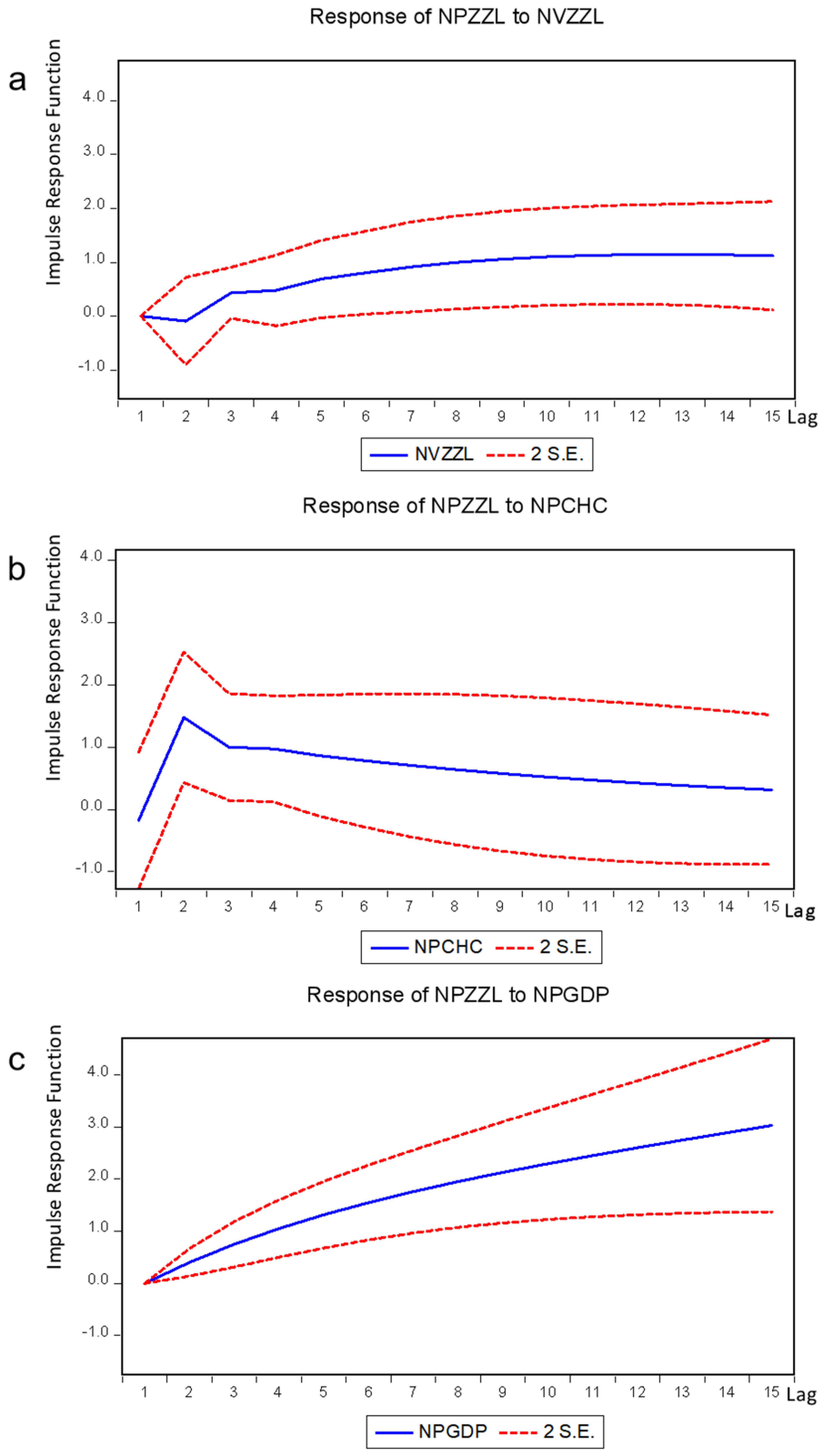

Figure 2 (**a**) Response of NPZZL to NVZZL perturbation. (**b**) Response of NPZZL to NPCHC perturbation. (**c**) Response of NPZZL to NPGDP perturbation. Blue line is trace of impulse response values, between the red dotted lines are the response standard errors. NPZZL represents the number of pharmacists, NVZZL represents the number of hospital visits, NPCHC represents per capita health expenditure, and NPGDP represents per capita GDP.

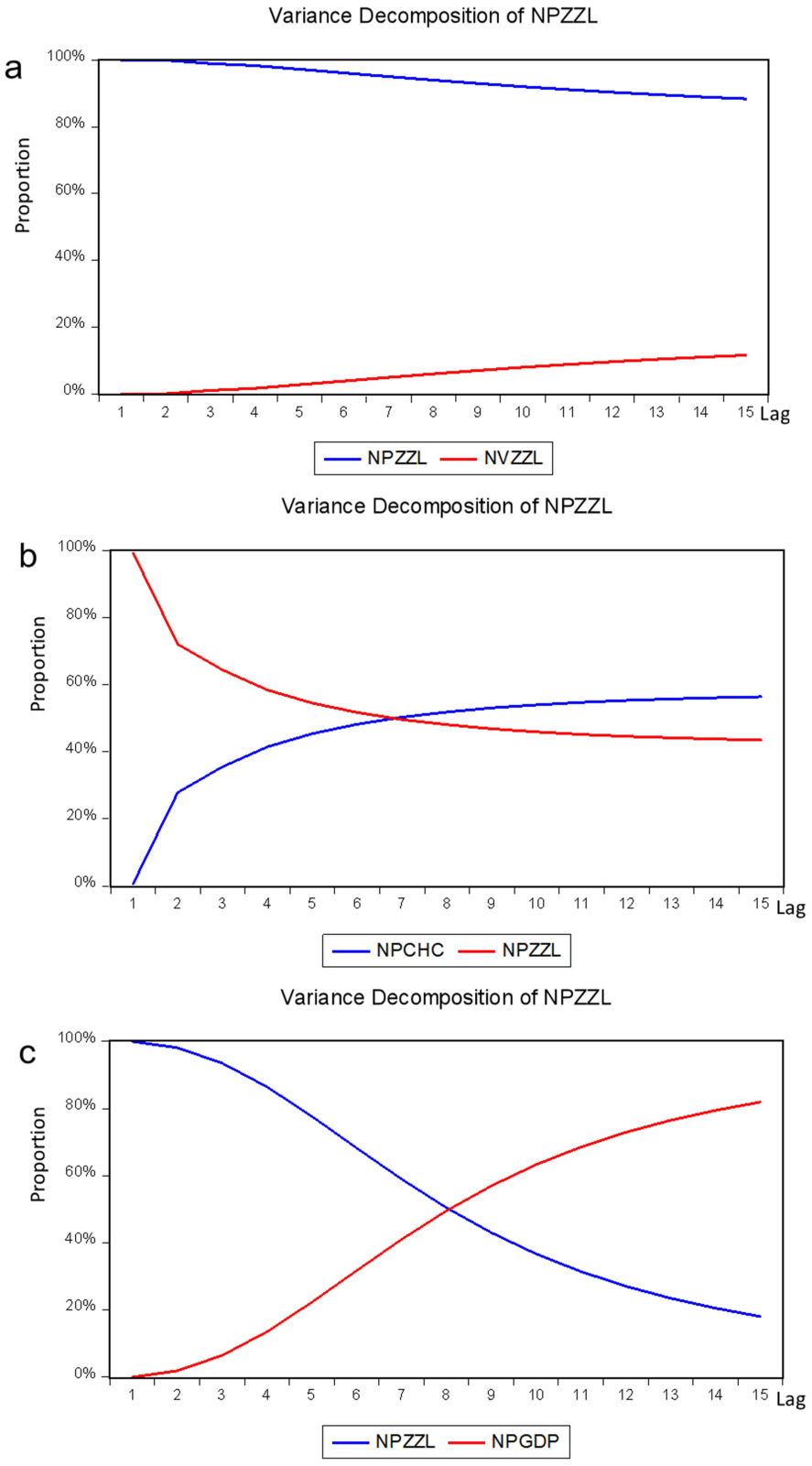

Figure 3 Variance decomposition of NPZZL. (**a**) Variance decomposition of NPZZL and NVZZL. (**b**) Variance decomposition of NPZZL and NPCHC. (**c**) Variance decomposition of NPZZL and NPGDP. NPZZL represents the number of pharmacists, NVZZL represents the number of hospital visits, NPCHC represents per capita health expenditure, and NPGDP represents per capita GDP.

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various factors affecting the expansion of the pharmacist team from a macroscopic perspective and can provide references for similar studies in the future.

Researchers do not focus on the coefficients of each equation in the VAR model because there are too many of them. Instead, they use tools like Granger causality tests, IRFs, and variance decomposition to interpret the model.[18] These tools help them understand the dynamic effects of random disturbances on the variable system. This study establishes a long-term equilibrium relationship among per capita health expenditure, per capita GDP, number of hospital visits, and number of pharmacists through ADF stationarity test and cointegration analysis. A VAR model can be established and run. The stationarity test shows all unit roots are within the unit circle, meaning the VAR model is stationary and subsequent analysis can be conducted. The results of the subsequent analysis are reasonable.

This study shows that there is a cointegration relationship between the development of the number of pharmacists and per capita health expenditure, per capita GDP, and the number of hospital visits. There is a one-way Granger causality relationship between the number of hospital visits, per capita health expenditure and the number of pharmacists, while there is no Granger causality relationship between per capita GDP and the number of pharmacists. The cointegration relationship indicates that there is a certain long-term relationship between the relevant factors and the number of pharmacists. The Granger causal relationship further confines and clarifies the relationship between the two variables. The Granger causal relationship shows that the previous information of the variables will affect the current development of the number of pharmacists, which is a prediction from another dimension. It should be noted that the Granger causal relationship is not a logical causal relationship.[39] IRF showed that more hospital visits and higher per capita GDP positively promote the pharmacist workforce. Per capita health expenditure increases the number of pharmacists in the short term. Variance decomposition analysis of influencing factors revealed that per capita health expenditure and per capita GDP significantly promote the positive growth of the pharmacist workforce, while the number of hospital visits contributes relatively less.

The number of hospital visits is a Granger cause of the number of pharmacists, indicating that as medical service demand grows, the pharmacist team must expand. For example, in some large general hospitals, the number of patients rising has dramatically increased the workload of outpatient and inpatient pharmacies, correspondingly increasing the demand for pharmacists who can dispense prescriptions and provide medication consultation. Therefore, when planning personnel allocation, medical institutions should base pharmacist recruitment and post settings on historical data and predicted growth trend of outpatient and inpatient visits to ensure patient medication safety and rational medication guidance. There is a one-way Granger causal relationship between per capita health expenditure and the number of pharmacists, and it only leads to an increase in the number of pharmacists in the short term. This means that when per capita health expenditure increases, more resources will be invested in the field of pharmaceutical services in the short term, such as purchasing advanced drug dispensing equipment and carrying out pharmacist training programs, thus promoting the short-term expansion of the pharmacist team. However, in the long run, its driving effect on the growth of the number of pharmacists may weaken due to the adjustment of the cost allocation structure or other factors. Health policy makers can take advantage of this relationship. When making health budgets and resource allocation plans, they can focus on short-term investment in pharmaceutical services. For example, providing special subsidies to attract pharmacist talents can quickly expand the pharmacist team and improve its quality, meeting short-term pharmaceutical service demands. However, it's also important to plan for the long term and explore sustainable development mechanisms for the pharmacist team to avoid instability due to short-term investment fluctuations. Although there's no Granger causal relationship between per capita GDP and the number of pharmacists, there is a cointegration relationship. From the results of the impulse response function and variance decomposition, it can be seen that the increase in the number of pharmacists happens alongside the growth of per capita GDP. Per capita GDP has a relatively large positive impact on the number of pharmacists, which will be greater than the influence of the number of pharmacists themselves. At the macro level, as regional per capita GDP increases, the demand for health services from residents has upgraded, placing higher requirements on the professional, accurate, and personalized pharmaceutical services provided by pharmacists. This prompts medical institutions to continuously optimize the pharmacist team structure, increase the proportion of highly qualified and skilled pharmacists, and promote the improvement of the overall quality and expansion of the pharmacist team scale. Pascal Zurn's research showed there's a connection between a country's economic development and its health

human resources.[6] Countries with higher per capita GDP spend more on healthcare and usually have more health workforce. This supports our findings. Wu Ning and Zhang Guangpeng also found that health human resources and factors like health expenses, social and economic development, and medical institutions' revenue and expenditure have a mutually beneficial effect.[40] All these findings align with ours. As health expenses grow, people's health service demands increase, leading to corresponding requirements for health human resource allocation. Social and economic development also raises health service demands and requirements for health human resources allocation.

This study also has certain limitations. The VAR model determines the dynamic relationship among variables through the statistical characteristics of data, and it is unable to clearly expound the dynamic influence process of economic indicators on the number of pharmacists from the perspectives of economic theory and human resources theory. In addition, due to the change in the statistical caliber of the health department in 2007, the number of pharmacists in this study has been affected. Dispensing staff who did not obtain the professional title qualification in hospitals but assisted pharmacists in their work were no longer included in the statistical scope of the number of pharmacists. As a result, the number of pharmacists decreased significantly compared with that of the previous year. In 2020, the number of hospital visits decreased significantly due to the impact of the COVID-19 pandemic. These abnormal observed values may affect the stable development of the time series and further prevent the model from accurately capturing the relationship among variables. Finally, there are many factors that influence the development of the number of pharmacists, such as per capita medical insurance expenses, the frequency of drug use, etc. Since multi-faceted exploration and further mining are required, this paper will not discuss them for the time being.

The article's data can help the government and health departments make better decisions about managing pharmacist resources. This information is important for the development of the pharmacist team. Future studies will explore more factors that affect the growth of pharmacists and improve the prediction model.

Conclusion

In summary, by modeling per capita health expenditure, per capita GDP, number of hospital visits, and number of pharmacists, this article finds that per capita health expenditure, per capita GDP, and number of hospital visits all have a positive promoting effect on the development of the number of pharmacists. Among them, the positive impacts of per capita GDP and number of hospital visits on pharmacists persist for a relatively long time, while per capita health expenditure only has a positive impact on the number of pharmacists in the short term. Among the selected indicators, the main contributions to the development of the number of pharmacists come from per capita health expenditure and per capita GDP, while the contribution of the number of hospital visits to the number of pharmacists is relatively small. These conclusions are of great significance for optimizing the rational allocation of pharmacist human resources and meeting the public's demand for pharmaceutical services. Given the complex factors influencing the development of the number of pharmacists, we welcome various research teams to provide suggestions and support regarding the relevant factors affecting the number of pharmacists.

Data Sharing Statement

The study was based on open-source data, users can download relevant data freely for research and publish relevant articles.

Ethics Approval and Consent to Participate

This study was certified as exempt from the ethical review by the Research Ethics Committee of Suqian Hospital of Nanjing Drum-Tower Hospital Group. This is because the study was based on open source data, users can download relevant data for free for research and publish relevant articles, so there are no ethical issues.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically

reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no competing interests in this work.

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