

Research on the Efficiency of Health Output from Local Healthcare Investments—Examining the Dual Moderating Effects of Aging and Environmental Quality

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Abstract. Based on the "Healthy China 2030" strategic framework, this study investigates the relationship between local healthcare investment and health output efficiency using panel data from 31 Chinese provinces (2012–2022). Through multiple linear regression analysis, we examine the intrinsic linkage between local government healthcare expenditures and health output efficiency, alongside the moderating effects of elderly population proportions by age cohort and environmental quality. Results indicate that increased healthcare spending significantly enhances health output efficiency, with particularly pronounced benefits in central and western regions. Rising aging rates exert an adverse moderating effect, while improved environmental quality positively moderates this relationship. Notably, the proportion of the population aged 75–84 most substantially diminishes expenditure efficiency. We recommend flexible allocation of healthcare expenditures based on regional aging patterns and an integrated mechanism linking environmental quality to government performance assessment, thereby optimizing fiscal efficiency and maximizing health output.

Keywords: Local healthcare expenditure, Health output efficiency, Aging rate, Environmental quality, Moderating effect

1. Introduction

Healthcare services, as a critical domain impacting public welfare, economic prosperity, and social stability, remain a global priority for development. The 19th CPC National Congress explicitly proposed implementing the "Healthy China Strategy," shifting public health services from treatment-centered to health-centered paradigms [1]. Within this context, local governments have assumed an increasingly prominent role in public health expenditure. Following the 1994 tax-sharing reform, local governments became primary providers of public health services. From 2012 to 2022, local government public health spending surged from ¥760.9 billion to ¥2,028.8 billion—a 2.7-fold increase—accounting for 90% of total public health expenditure by 2022[2].

Concurrently, rising healthcare expenditures face intensifying efficiency pressures from population aging and environmental volatility. National Bureau of Statistics data reveal that by late 2024, China's population aged 60+ reached 310.31 million (22.0% of the total), signaling imminent

entry into a deeply aging society. Escalating aging and evolving senior consumption demands drive growth in diversified, multi-tiered health services, inevitably increasing medical costs. An OECD report indicates that 50% of age-related fiscal expenditure growth (2000–2050) stems from healthcare and long-term care. Simultaneously, environmental quality significantly impacts public health: approximately 9 million global deaths in 2015 were attributed to hazardous air, water, and soil pollutants [3].

While existing research acknowledges the positive impact of government healthcare spending on health outcomes, few studies holistically examine the moderating effects of multi-stage aging dynamics and environmental quality. This study innovatively segments the elderly population by age cohort to rigorously examine differential impacts of each group's proportion on expenditure efficiency, while comprehensively evaluating environmental quality's moderating role. Our findings provide targeted empirical evidence for optimizing healthcare resource allocation and enhancing fiscal efficiency.

2. Theoretical analysis and research hypotheses

2.1. Government healthcare expenditure and health output efficiency

Following the 1994 tax-sharing reform, information asymmetry and technological disparities have positioned local governments as more effective providers of public resources than the central government. Their proximity enables superior understanding of resident preferences, and fiscal decentralization empowers them to enhance resource allocation efficiency through localized infrastructure and public service delivery. Local government healthcare expenditure refers specifically to fiscal appropriations allocated for healthcare initiatives [4]. Empirical consensus confirms that such expenditure boosts health output efficiency, elevating population health levels. Increased spending manifests in key indicators: rising life expectancy [5-6] and declining perinatal/maternal mortality rates [7], collectively driving health output efficiency gains. Regional heterogeneity exists, however, with eastern China's output elasticity proving lower than central/western regions [7-8]. Spatially, government health investment exhibits positive spillover effects and time-lagged impacts, whereby current-period spending influences neighboring regions' future health outcomes [8]. Thus, we posit:

H1: Local government healthcare expenditure positively affects health output efficiency.

2.2. Aging, healthcare expenditure, and health output efficiency

Regarding aging's interplay with healthcare spending and health efficiency, three international perspectives dominate:

- Gruenberg's "Expansion of Morbidity Hypothesis"[9]: Extended lifespans increase morbidity/disease duration, where "unhealthy aging" escalates healthcare costs.
- Fries' "Compression of Morbidity Hypothesis"[10]: Medical advances and healthy lifestyles compress disease/disability duration, yielding "healthy aging" that reduces expenditures.
- Manton's "Dynamic Equilibrium Hypothesis"[11]: Disability duration expands but severity declines, stabilizing healthcare spending.

Domestically, studies link aging to rising health service demand and costs [12], with empirical evidence confirming positive correlations between aging levels and health expenditures [13-14]. This effect proves more pronounced in urban/high-income regions than rural/low-income areas [14-15]. Conversely, other scholars attribute cost growth primarily to proximity to death rather than age

itself [16]. Existing research predominantly examines aggregate aging trends, neglecting empirical analysis of how specific age cohorts moderate fiscal expenditure–health efficiency relationships. Hence, we propose:

H2: Accelerated aging exerts a negative moderating effect between local healthcare investment and health output efficiency.

2.3. Environmental quality, healthcare expenditure, and health output efficiency

Environmental pollution adversely impacts public health, thereby exerting significant positive pressure on healthcare expenditures [17]. While economic development exacerbates pollution, it concurrently expands government health spending. Such spending improves medical services, potentially offsetting pollution-induced health damage [18]. Most pollution studies focus on air quality, revealing regional divergence: in southern China, increased emissions inhibit public health spending growth, whereas northern emissions stimulate it [19]. Industrial pollution—constituting >70% of China’s contaminants—severely damages health and ecosystems [20]. Limited research examines industrial wastes’ (waste gas, wastewater, solid waste) health impacts. Consequently, we hypothesize:

H3: Environmental quality improvement positively moderates the relationship between local healthcare investment and health output efficiency.

3. Model construction and sample selection

3.1. Regression model construction

3.1.1. Two-way fixed effects model

To investigate the impact of public healthcare expenditure on health output efficiency, this study employs a two-way fixed effects panel data model. This model controls for unobservable time and individual fixed effects, mitigating omitted variable bias and endogeneity issues, thereby enhancing the reliability of findings.

The mathematical expression is:

$$Heal_{it} = \beta_0 + \beta_1 PE_{it} + \Gamma X_{it} + f_t + \mu_i + \varepsilon_{it} \quad (1)$$

In the model, i denotes provinces, t denotes years, and $Heal_{it}$ represents health output efficiency, the core dependent variable of this study. Health output encompasses three dimensions of public health welfare: life expectancy, incidence rates of Category A and B infectious diseases, and per capita medical visits.[20] According to a scholar's research in 2019 [19], this study proxies $Heal_{it}$ using per capita outpatient and emergency visits, calculated as total outpatient/emergency visits divided by year-end resident population (data sourced from the China Health Statistical Yearbook).

PE_{it} , the core explanatory variable, measures local government healthcare expenditure. To minimize measurement error, we use the natural logarithm of per capita local government healthcare expenditure (published by the National Bureau of Statistics).

X_{it} denotes control variables, with Γ as their coefficient vector. Referencing the research from two papers[7,21], and considering data availability, we include:

- Per capita GDP (LnRGDP)
- Urbanization rate (City)

- Medical insurance coverage (CI)
- General practitioners per 10,000 people (Doc)
- Hospital beds per 10,000 people (LnBed)
- Average education years for population aged 6+ (LnScho).

These variables control for economic development, education, healthcare resources, medical security, and urbanization. The model incorporates two-way fixed effects: f_t (time effects), μ_i (province-specific individual effects), and ε_{it} (random error term).

3.1.2. Moderating effects model

To explore the moderating roles of aging and environmental quality, we extend Equation (1) by introducing interaction terms:

$$Heal_{it} = \gamma_0 + \gamma_1 PE_{it} + \gamma_2 (PE_{it} \times Old_{it}) + \gamma_3 (PE_{it} \times Pollution_{it}) + \phi X_{it} + f_t + \mu_i + \varepsilon_{it} \quad (2)$$

Here:

- $PE_{it} \times Old_{it}$: Interaction between healthcare expenditure and aging rate. Aging is stratified into three groups: 65–74 (Old1), 75–84 (Old2), and ≥ 85 (Old3).

- $PE_{it} \times Pollution_{it}$: Interaction between healthcare expenditure and environmental quality. Environmental quality (Pollution) is measured via an entropy-weighted composite score of industrial three wastes (waste gas, wastewater, solid waste), following a scholar's study in 2022. [22]

This study employs Stata software and applies a simple linear regression approach to examine the moderating effects of aging rates and environmental quality. First, Model (1) specifies health output efficiency as the dependent variable, where the coefficient β_1 captures the overall impact of government healthcare expenditure on health output efficiency. Second, Model (2) incorporates both government healthcare expenditure and its interaction terms with aging rates and environmental quality. Here, γ_2 and γ_3 represent the moderating effects of aging rates and environmental quality, respectively, on the relationship between government healthcare expenditure and health output efficiency.

3.2. Sample selection

This study utilizes panel data from 31 provincial-level administrative regions in China (2012–2022) as the initial sample. Data were extracted from the China Statistical Yearbook, China Health Statistical Yearbook, China Population and Employment Statistical Yearbook, China Education Statistical Yearbook, and China Environmental Statistical Yearbook, yielding 341 province-year observations. For the environmental quality metric, the composite "industrial wastes" (waste gas, wastewater, solid waste) indicator was replaced with an Environmental Composite Score derived through the entropy weight method. To minimize data inaccuracies affecting model estimates, the following technical preprocessing was applied prior to regression analysis:

1. Winsorization: The urbanization rate was winsorized at the 5% and 95% levels to mitigate extreme values.

2. Logarithmic Transformation: Variables including per capita GDP, average education years for the population aged 6+, and hospital beds per 10,000 people were log-transformed to capture nonlinear relationships with health outcomes and control heteroscedasticity-induced bias.

Final variable specifications are presented in Table 1.

Table 1: Variable definitions

Variable Type	Variable Name	Symbol	Definition
Dependent	Health output efficiency	Heal	Outpatient/emergency visits per capita
Independent	Government healthcare expenditure	PE	Ln(Government healthcare expenditure per capita)
Moderators	Aging rate (65–74)	Old1	% of population aged 65–74
	Aging rate (75–84)	Old2	% of population aged 75–84
	Aging rate (≥85)	Old3	% of population aged ≥85
Controls	Environmental quality	Pollution	Entropy-weighted industrial three wastes score
	Economic development	LnRGDP	Ln(Per capita GDP)
	Education level	LnScho	Ln(Average education years for population ≥6)
	Medical resources	Doc	General practitioners per 10,000 people
		LnBed	Ln(Hospital beds per 10,000 people)
	Urbanization rate	City	Urban population share (%)
	Medical insurance	CI	Urban basic medical insurance coverage (%)

4. Empirical results analysis

4.1. Descriptive statistics

Table 2: Descriptive statistics

Variable	N	Mean	SD	Min	p50	Max
Heal	341	5.26	1.82	2.48	4.87	11.32
PE	341	0.12	0.06	0.04	0.11	0.53
LnBed	341	4.01	0.20	3.30	4.02	4.43
Doc	340	1.93	1.17	0.11	1.67	6.90
Old1	341	9.02	13.42	3.48	7.09	170.8
Old2	341	4.17	6.86	1.41	3.30	87.99
Old3	341	1.82	8.25	0.24	0.84	118.1
LnRGDP	341	10.90	0.45	9.85	10.86	12.15
LnScho	341	2.21	0.13	1.44	2.22	2.55
City	341	0.60	0.12	0.41	0.59	0.87
CI	341	0.71	0.30	0.16	0.86	1.11

Key observations:

- Heal (per capita visits) shows substantial variability (SD=1.82), reflecting regional heterogeneity.
- PE (healthcare expenditure) ranges from 0.04 to 0.53, indicating significant interprovincial disparities.

4.2. Baseline regression

Table 3: Baseline regression and robustness tests

	(1) Heal	(2) Heal1 (2017–2022)	(3) Dead (Maternal Mortality)
PE	-2.770*** (0.819)	-2.060** (1.024)	-3.168*** (1.031)
Controls	Included	Included	Included
Fixed Effects	Year + Province	Year + Province	Year + Province
R2	0.974	0.979	0.865
N	340	185	340

Key findings:

- A 1-unit increase in PE reduces per capita visits by 2.77 ($p < 0.01$), supporting H1.
- Economic development (LnRGDP) and education (LnScho) positively affect visits, while medical insurance (CI) shows a negative effect.

4.3. Robustness tests

- Subsample analysis (2017–2022): Results remain consistent ($\beta = -2.06, p < 0.05$).
- Alternative dependent variable (maternal mortality): PE significantly reduces mortality ($\beta = -3.168, p < 0.01$), confirming robustness.

4.4. Heterogeneity analysis

Table 4: Regional heterogeneity

	Eastern	Central	Western
PE	-2.142 (1.335)	-6.520** (2.816)	-3.311** (1.378)
N	121	99	120

- Central and western regions show stronger negative effects ($p < 0.05$), attributed to lower baseline healthcare resources.

4.5. Moderating effects

Table 5: Moderating effects of aging and environmental quality

	(1) Old1	(2) Old2	(3) Old3
PE × Old	0.154*** (0.0375)	0.365*** (0.0918)	0.241*** (0.0571)
PE × Pollution	-8.177** (3.666)	-7.639** (3.621)	-7.783** (3.689)

- Aging (Old2: 75–84) exerts the strongest negative moderation ($\gamma=0.365, p<0.01$), validating H2.
- Environmental improvement (Pollution) shows positive moderation ($\gamma=-7.783, p<0.05$), supporting H3.

5. Conclusion and limitations

Against the backdrop of Healthy China initiatives and expanding government health expenditure, this study analyzes 2012–2022 panel data from 31 Chinese provinces. Results confirm that increased local healthcare spending significantly benefits public health, yielding three key conclusions:

5.1. Local healthcare expenditure robustly enhances health output efficiency

A 1% rise in per capita local healthcare spending reduces average outpatient visits by 0.0277, indicating strong positive efficiency gains—consistent with prior findings [6]. Regionally, effects are insignificant in eastern China but pronounced in central/western regions, attributable to disparities in economic development, medical resources, service accessibility, and preventive health awareness.

- Policy Recommendations: Prioritize cross-departmental coordination to maximize efficiency, targeting aging needs and environmental risk compensation.
- Implement region-specific policies: Eastern China: Shift focus from scale expansion to quality enhancement (e.g., smart healthcare, precision prevention, advanced R&D), reducing redundant expenditures.
- Central/Western China: Strengthen regional medical hubs via increased GPs per 10,000 people and interprovincial collaboration in central area (e.g., tier-3 hospitals supporting grassroots facilities). While deploy central transfers for county-level medical IT upgrades, telemedicine networks, and standardized emergency systems in Western area.
- Launch Flexible Talent Mobility Programs: Offer incentives (e.g., promotion priority, salary subsidies) for medical professionals serving ≥ 3 years in central/western regions.

5.2. Aging exerts a negative moderating effect on expenditure-health efficiency

The proportion of the population aged 75–84 most substantially diminishes efficiency, reflecting delayed disease onset amid extended lifespans versus rapid growth of the elderly cohort—aligning with existing evidence [12–13].

Policy Recommendations: Develop an "Aging Adaptation Coefficient" using big data to dynamically adjust expenditures based on regional aging severity. Optimize resource allocation to prevent inefficiency (e.g., overinvestment in underutilized facilities) [23–24]. Reorient spending toward preventive care and chronic disease management, establishing elderly health big-data platforms for risk prediction. Scale telemedicine and AI diagnostics in central/western regions, supplemented by fiscal incentives to attract talent to high-aging areas.

5.3. Environmental quality positively moderates expenditure-health efficiency

Improved environmental conditions reduce health risks and enhance living standards, significantly optimizing health output efficiency—validating previous research [18].

- Policy Recommendations: Establish fiscal feedback mechanisms (e.g., pollution fines → health funding) and cross-regional ecological compensation for environmentally protected areas.

- Integrate environment-health governance: Include PM_{2.5}, water safety, etc., in local government performance evaluations. Launch community-based health education initiatives (e.g., smog protection, water safety). Operationalize the "Two Mountains" Theory from the 20th CPC National Report, institutionalizing ecological priorities.

5.4. Limitations

Data constraints (e.g., cross-province medical visits, missing variables) may affect precision. Future studies should refine metrics for patient origins and cross-regional care.

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