

From Price Governance to Spatial Equity: A Study on the Spatial Equity Effects of Volume-Based Procurement for Coronary Stents in China

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From Price Governance to Spatial Equity: A Study on the Spatial Equity Effects of Volume-Based Procurement for Coronary Stents in China

Abstract

Background: For decades, the high cost of medical devices and the geographic stickiness of high-quality healthcare resources have substantially constrained equitable access to percutaneous coronary intervention (PCI) among patients with coronary heart disease in China.

Objective: This study aims to systematically evaluate the profound impact of the national volume-based procurement (VBP) policy for coronary stents on the spatial equity of high-value medical consumables, and to elucidate the underlying structural evolution of inequality patterns.

Methods: A retrospective longitudinal design was employed. Procurement data on coronary stents were collected from 2,261 healthcare institutions across 31 provinces in China for 2019 (pre-VBP) and 2021 (post-VBP). Key indicators included per capita affordability of stents and procurement volume. Inequality and spatial distribution were assessed using the Gini coefficient, Theil index decomposition, and spatial autocorrelation analysis, including Global Moran's I and Local Indicators of Spatial Association (LISA), to examine regional disparities and spatial clustering patterns.

Results: Following the implementation of VBP, the average price of winning stents declined by more than 90%, while per capita affordability increased by 58.73-fold. The proportion of high-quality alloy stents surged from 65.76% to 98.59%. Theil

index decomposition revealed a structural reversal in the drivers of inequality: the dominant source shifted from inter-regional (macro-level) disparities in 2019 to intra-provincial (micro-level) disparities in 2021. Spatial autocorrelation analysis further showed that Moran's I decreased from 0.2996 to 0.1440, indicating a substantial disruption of the previously pronounced macro-level geographic clustering.

Conclusions: The VBP policy significantly improved the accessibility of coronary stents and facilitated an upgrade in the quality of clinical consumables. More importantly, it induced a structural shift in the drivers of inequality in healthcare resource allocation in China—from macro-level regional disparities to intra-provincial micro-level disparities.

Keywords:

Volume-based Procurement; Coronary Stent; Spatial Equity; Equity in Resource Allocation; Theil Index

1. Introduction

Coronary artery disease (CAD) remains the leading cause of mortality worldwide, accounting for approximately 9 million deaths annually^[1,2]. In China, the burden of CAD has continued to escalate, with an estimated 11.4 million patients affected. Notably, the hospitalization rate for acute ST-segment elevation myocardial infarction (STEMI) has increased nearly fortyfold over the past decade^[3]. Although PCI with drug-eluting stent (DES) implantation has been clinically established as the gold standard for improving patient outcomes^[4,5], its widespread adoption has long been

89 constrained by the high cost of medical devices. Prior to 2020, the annual
90 procurement expenditure for coronary stents in China reached approximately 15
91 billion RMB, accounting for nearly one-tenth of the total national expenditure on
92 high-value medical consumables. This substantial financial burden not only imposed
93 significant out-of-pocket costs on patients but also markedly increased the risk of
94 catastrophic health expenditure and medical impoverishment^[3,5,6].

95 In response to the rapid growth in healthcare expenditures, countries worldwide have
96 explored diverse price regulation strategies. In 2017, India incorporated coronary
97 stents into its National List of Essential Medicines and implemented a price-capping
98 policy, achieving a reduction of up to 85%^[6,7]. However, subsequent evidence
99 suggests that healthcare providers may offset revenue losses by increasing charges for
100 ancillary services, thereby limiting the net reduction in patients' overall
101 expenditures^[8]. Japan has adopted a Foreign Price Adjustment (FPA) mechanism,
102 which sets reimbursement ceilings based on international reference pricing;
103 nevertheless, the pace of price reduction under this approach has been relatively
104 gradual^[9,10]. In Europe and the United States, Group Purchasing Organizations (GPOs)
105 are commonly used to negotiate prices through market-based mechanisms. Yet, in the
106 absence of strong administrative intervention, substantial inter-regional price
107 variations for comparable devices persist^[11]. In contrast, China has pioneered a
108 government-led VBP model, which leverages extensive demand aggregation to
109 enhance bargaining power. The intensity of this policy intervention and the magnitude

of resulting price reductions render it a highly distinctive and valuable case for research in the field of global health governance.

Beyond financial barriers, the geographic stickiness of healthcare resource allocation constitutes another critical impediment to health equity in China. High-quality medical resources—including advanced catheterization laboratories and experienced interventional cardiologists—have long been disproportionately concentrated in the more developed eastern regions, resulting in a pronounced “east–west gradient” in the availability and utilization of PCI services^[2,12]. Prior to the implementation of VBP, the high price of coronary stents, compounded by weaker health insurance capacity in less developed regions, further amplified the “healthcare divide” between rural areas in central and western China and urban centers in the east^[12,13]. This spatial inequality has placed patients in remote and underserved regions at a substantially higher disease burden when confronted with coronary artery disease^[14,15].

In response, the Chinese government officially launched the national VBP program for coronary stents in 2020, marking a transition of healthcare reform into a “deep-water phase” aimed at restructuring the market for high-value medical consumables^[2,16]. The policy prioritized clinically validated, high-quality alloy drug-eluting stents and leveraged a “volume-for-price” strategy to reduce average stent prices from tens of thousands of RMB to the range of a few hundred RMB, with an average reduction exceeding 90%^[15–18]. In conjunction with the “zero-markup” policy for medical consumables, VBP was designed to eliminate inflated price components across both procurement and distribution channels, thereby establishing

an economic foundation for nationwide resource redistribution^[21]. Although existing studies have demonstrated the short-term effectiveness of VBP in terms of price reductions, savings in health insurance expenditure, and changes in cost structures within specific healthcare institutions^[17,19,21], critical research gaps remain. In particular, there is a lack of nationwide, longitudinal quantitative evidence assessing the policy's impact from the perspective of spatial equity and the structural transformation of distributive inequality. As stent prices have become highly homogenized nationwide, it remains unclear whether resource allocation has genuinely broken the prior pattern of geographic clustering^[22], and whether the drivers of inequality have shifted from traditional macro-level regional disparities to intra-provincial, micro-level dynamics shaped by endogenous factors^[23]. To address these gaps, this study utilizes national procurement data from 2019 to 2021 and applies a suite of analytical methods—including the Gini coefficient, Theil index decomposition, and spatial autocorrelation analysis (Moran's I)—to systematically evaluate the impact of VBP on the spatial equity of coronary stent allocation in China, and to elucidate the evolving structural dynamics of inequality.

2. Methods

2.1 Data Sources and Study Design

This study employed a retrospective longitudinal design to comparatively analyze the procurement characteristics of coronary stents in China before and after the implementation of the national VBP policy for high-value medical consumables, specifically in 2019 (pre-policy) and 2021 (post-policy). The study sample comprised

2,261 healthcare institutions across 31 provincial-level administrative regions in mainland China (excluding Hong Kong, Macao, and Taiwan). Procurement data were obtained from the National Joint Procurement Office for High-Value Medical Consumables and included detailed information on unit prices, procurement volumes, material composition, and country of origin of coronary stents. Provincial-level gross domestic product (GDP) and per capita annual disposable income were sourced from the China Statistical Yearbook.

In accordance with official geographic and economic regional classifications in China, the 31 provinces were categorized into three regions: eastern ($n = 11$), central ($n = 9$), and western ($n = 11$). The eastern region included Shanghai, Beijing, Tianjin, Shandong, Guangdong, Jiangsu, Hebei, Zhejiang, Hainan, Fujian, and Liaoning. The central region comprised Inner Mongolia, Jilin, Anhui, Shanxi, Jiangxi, Henan, Hubei, Hunan, and Heilongjiang. The western region encompassed Yunnan, Sichuan, Ningxia, Guangxi, Gansu, Tibet, Guizhou, Chongqing, Shaanxi, and Qinghai.

As this study was based exclusively on aggregated procurement data and did not involve individual-level biological or clinical information, ethical approval from an Institutional Review Board (IRB) was not required in accordance with relevant ethical guidelines.

2.2 Definition of Core Variables

The following indicators were selected as key variables to evaluate the policy effects:

Affordability Indicator: Affordability was defined as the number of coronary stents affordable per capita, which served as the primary outcome measure in this study. The calculation formula is as follows:

$$\text{Affordability} = \frac{\text{Annual Disposable income Per Capita}}{\text{Unit price of stent}} \quad (1)$$

Policy Implementation Indicators: These included the procurement unit price and the Bid-winning stent utilization rate, defined as the proportion of procured volume accounted for by bid-winning stents relative to total procurement volume.

Resource Allocation Indicators: These comprised per capita procurement volume (total provincial procurement volume divided by the resident population) and per capita procurement expenditure (total procurement spending divided by the resident population).

2.3 Measurement of Regional Equity

To assess the equity of the spatial distribution of the aforementioned variables, the following indices were employed:

2.3.1 Gini Coefficient

The Gini coefficient (G) was used to quantify the overall degree of inequality in distribution. The formula is expressed as follows:

$$G = \frac{1}{2n^2\bar{x}} \sum_{i=1}^n \sum_{j=1}^n |x_i - x_j|$$

Where n denotes the number of provinces, x_i and x_j represent the values of the indicator for different provinces, and $\bar{x}$ indicates the national mean level.

2.3.2 Theil Index Decomposition

The Theil index (T) was employed to identify the sources of inequality by leveraging its additive decomposability. The overall Theil index can be decomposed into within-region inequality (T_W) and between-region inequality (T_B):

$$T = T_W + T_B = \sum_{k=1}^m \left(\frac{n_k \bar{x}_k}{n \bar{x}} \right) T_k + \sum_{k=1}^m \frac{n_k \bar{x}_k}{n \bar{x}} \ln \left(\frac{\bar{x}_k}{\bar{x}} \right)$$

where m denotes the number of regions, n_k represents the number of provinces within region k , and T_k is the Theil index for that region. The relative contributions of within-region and between-region inequality to total inequality were quantified by calculating the ratios T_W/T and T_B/T , respectively.

2.4 Spatial Autocorrelation Analysis

2.4.1 Construction of Spatial Weight Matrix

An inverse distance spatial weight matrix (w_{ij}) was constructed in this study. The matrix elements were defined as $w_{ij}=1/d_{ij}$, where d_{ij} represents the geographic distance between the administrative centroids of provinces. This specification captures the spatial interaction mechanism whereby influence decays with increasing distance.

2.4.2 Spatial Statistical Inference

Global Moran's I statistic was applied to assess the overall spatial autocorrelation across provinces nationwide:

$$I = \frac{n \sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n \sum_{j=1}^n w_{ij} \sum_{i=1}^n (x_i - \bar{x})^2}$$

In addition, Local Indicators of Spatial Association (LISA) were employed to identify high-high (HH) and low-low (LL) spatial clusters, as well as spatial outliers.

2.5 Statistical Analysis and Software

The Kruskal–Wallis H test was used to assess differences in the distribution of key indicators across the three major regions. When the overall test indicated statistical significance ($P < 0.05$), post hoc pairwise comparisons were conducted using Dunn’s test with Bonferroni correction.

Data cleaning, statistical analyses, and the computation of inequality indices were performed using R (version 4.5.1). The construction of spatial weight matrices, spatial autocorrelation analyses, and the visualization of local clustering patterns were conducted using ArcGIS Pro. All statistical tests were two-tailed, with a significance level set at $\alpha = 0.05$.

3. Results

3.1 Price Changes and Procurement Distribution Characteristics

Following the implementation of the national VBP policy, the procurement price of coronary stents declined substantially. In 2021, the national average procurement unit price decreased by 77.10% compared with 2019 (Figure 1A). Among bid-winning products, the average price reduction reached 91.70% (range: 87.73%–95.84%), with the lowest unit price falling to RMB 458.99.

Stratified by material type, cobalt–chromium–platinum alloy stents exhibited the most pronounced price reduction ($>80\%$), significantly exceeding that observed for stainless steel and fully bioresorbable stents (14%–16%) (Supplementary Figure 1).

At the market structure level, a marked substitution effect was observed. The procurement share of high-performance cobalt–chromium–platinum alloy stents

(including those with durable and biodegradable coatings) surged from 65.76% in 2019 to 98.59% in 2021. In contrast, the proportion of conventional stainless steel stents (SS-stents) sharply declined from 34.14% to 1.26% (Supplementary Figure 2).

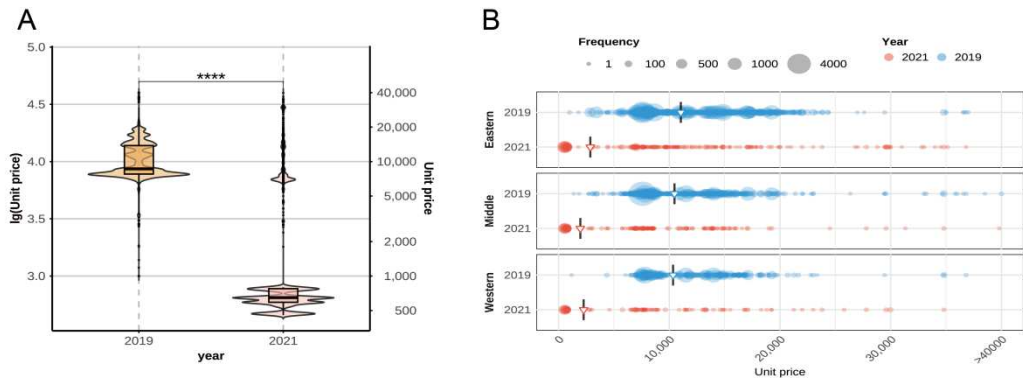


Figure 1. Distribution and comparison of coronary stent unit prices before and after the implementation of the national VBP policy.

Note:(A) Overall distribution changes in coronary stent unit prices. The left y-axis represents the log-transformed values of unit prices (lg(Unit price)), and the right y-axis represents the original unit prices (in CNY). (B) Price distribution of coronary stents across different regions (Eastern, Central, and Western). Inverted triangles and their associated horizontal lines represent the mean price for each respective year.

At the regional level, the distribution of stent prices in 2019 exhibited a clear gradient pattern, characterized by higher prices in the eastern region and lower prices in the western region (Figure 1B). The Kruskal–Wallis test confirmed that these differences were statistically significant ($H = 484.89, P < 0.001$).

By 2021, although statistically significant differences in price distributions across the three regions persisted ($H = 81.98$, $P < 0.001$), the median prices had largely converged (RMB 648 in the eastern region vs. RMB 645 in the central and western regions). The remaining statistical differences in 2021 were primarily attributable to regional variation in the utilization of non-winning, higher-priced products (Table 1).

Table 1 Comparison of stent prices by region

Year	Region	Mean	Median	SD	Kruskal–Wallis (H)
2019	Eastern	11047	8990 ^a	4176	484.885***
	Middle	10472	8633 ^b	3717	—
	Western	10343	8600 ^c	3350	—
2021	Eastern	2872	648 ^d	5376	81.976***
	Middle	1969	645 ^e	3939	—
	Western	2271	645 ^f	5201	—

Note: The Kruskal–Wallis test was used to evaluate differences in stent prices among the three regions (Eastern, Central, and Western) for each year. Pairwise comparisons were performed using the Dunn post-hoc test with Bonferroni correction. Different superscript letters (a–f) indicate significant differences between regions within the same year (a–e: $P < 0.001$; f: $P < 0.05$ for the comparison between Central and Western in 2021). Significance levels: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Concomitant with the substantial price reduction, notable shifts in the regional distribution of procurement volumes were observed. In 2021, the total national procurement volume increased compared with 2019; however, the share of

procurement attributable to the eastern region declined from 51.51% to 45.27%. In contrast, the central and western regions experienced absolute increases in procurement volume of 17.44% and 22.15%, respectively, with Yunnan Province exhibiting the largest (137.2%). Driven by the sharp decline in unit prices, total procurement expenditures in all regions were significantly lower in 2021 than in 2019 (Figure 2).

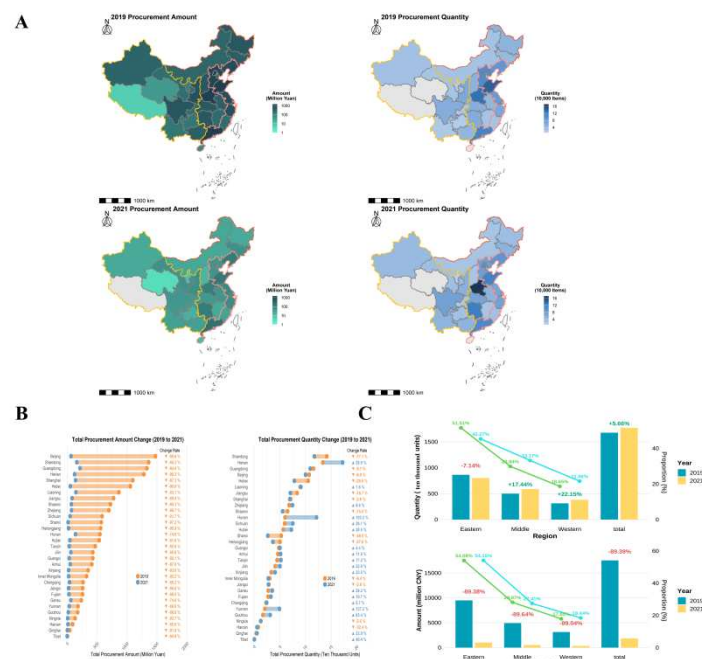


Figure 2. Spatiotemporal distribution and temporal trends of coronary stent procurement quantity and amount before and after the national VBP policy.

Note:(A) Spatial distribution of coronary stent procurement amount and quantity across Chinese provinces.(B) Changes in procurement amount and quantity by province.(C) Comparison of procurement quantity and amount across the Eastern, Central, and Western regions, and the national total.

Meanwhile, the national average bid-winning stent utilization rate rose markedly from

41.95% in 2019 to 95.77% in 2021. In 2019, there were significant regional differences in the bid-winning stent utilization rate ($H = 6.02$, $P = 0.049$). However, by 2021, these differences were no longer statistically significant ($H = 1.50$, $P = 0.473$), indicating a high degree of convergence across regions (Figure 3).

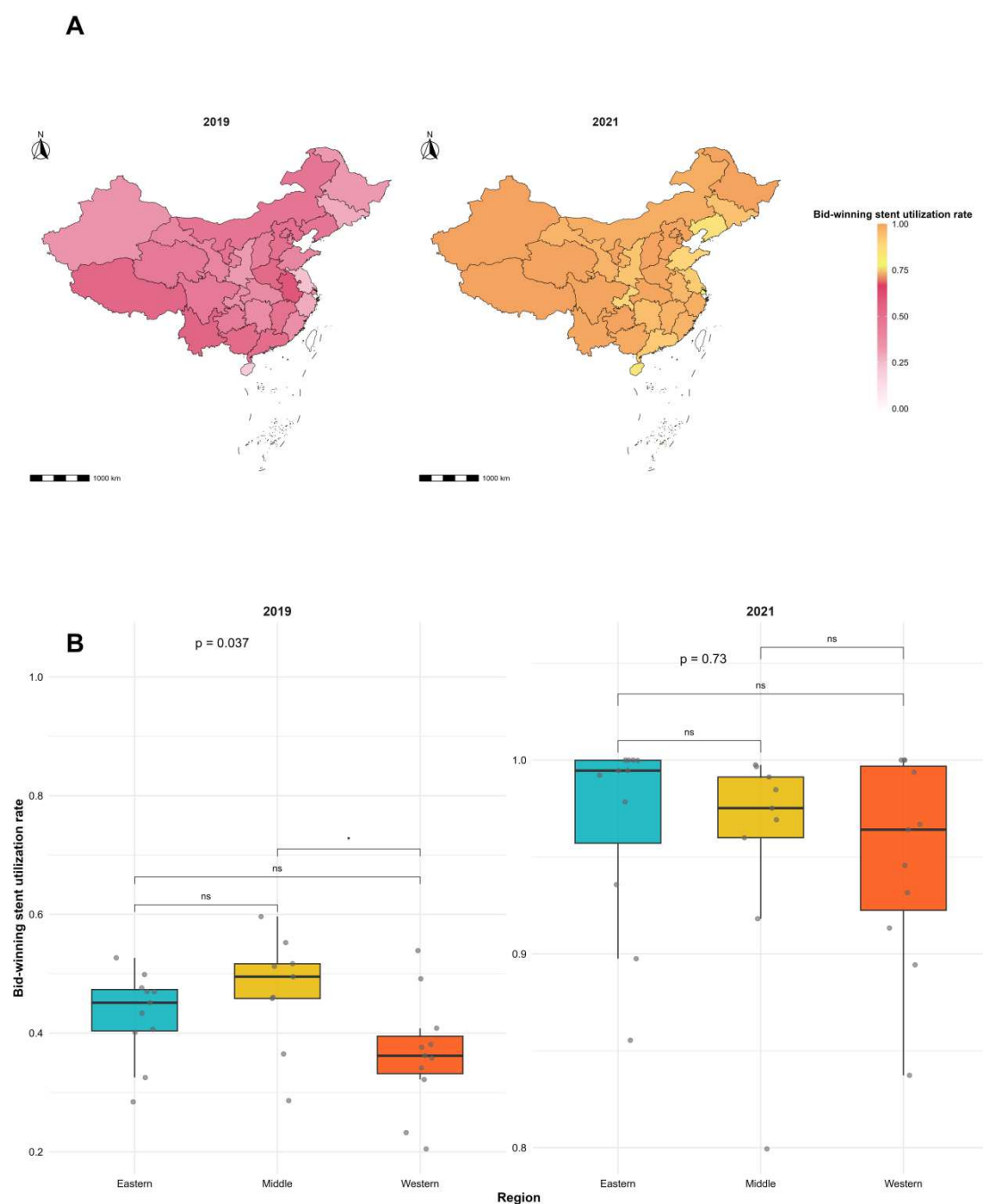


Figure 3. Spatial distribution and regional differences in the utilization rate of bid-winning

stents before and after the national VBP policy.

Note:(A) Spatial distribution of the bid-winning stent utilization rate across Chinese provinces.(B) Comparison of the bid-winning stent utilization rate among the Eastern, Central, and Western regions. The bid-winning stent utilization rate is defined as the proportion of the procurement volume of bid-winning stents to the total procurement volume.Significance levels: $*P < 0.05$, $**P < 0.01$, $***P < 0.001$; ns, not significant.

3.2 Evolution of Affordability and Inequality Structure

In 2021, the national average number of coronary stents affordable per capita increased by 58.73-fold compared with 2019. In 2019, a total of 26 provinces (83.9%) had fewer than five affordable stents per capita; by 2021, all observed provinces had exceeded this threshold (Figure 4).

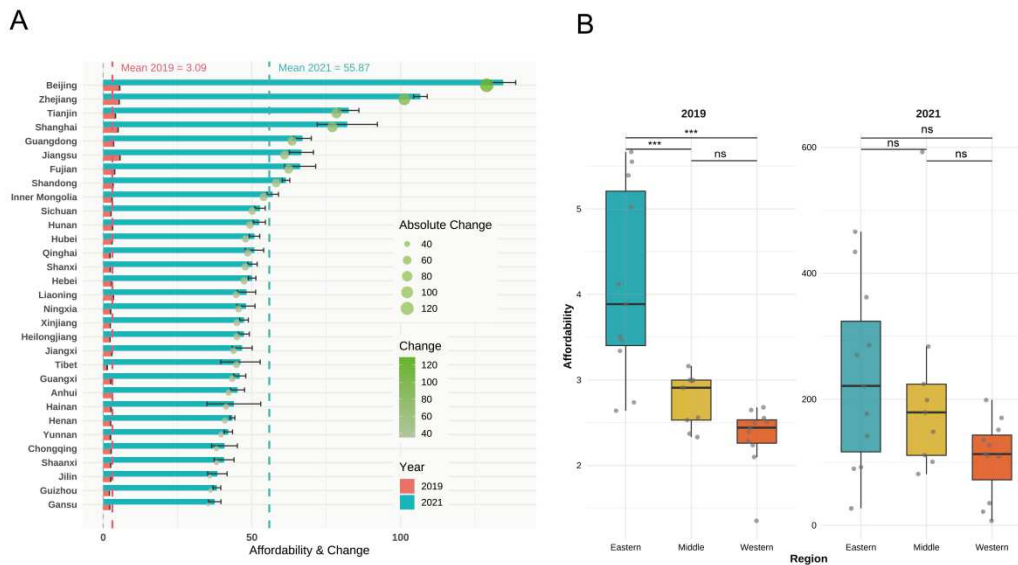


Figure 4. Affordability of coronary stents across provinces and regions before and after the national VBP policy.

Note:(A) Provincial-level changes in stent affordability.(B) Regional distribution and differences in stent affordability.Significance levels: *** $P < 0.001$; ns, not significant.

In terms of relative inequality, the Gini coefficient for affordability increased from 0.172 in 2019 to 0.379 in 2021, while the Theil index rose from 0.052 to 0.243. Decomposition of the Theil index revealed a structural shift in the sources of inequality. In 2019, overall inequality was primarily driven by between-group (inter-regional) disparities, which accounted for 61.54% of total inequality. By 2021, this pattern had reversed, with within-group (intra-regional) disparities becoming the dominant contributor, accounting for 78.60% of total inequality (Table 2).

Table 2. Provincial-level affordability inequality indices and Theil index decomposition

Indicator Category	Index	2019	2021	Change (%)	2021 Contribution (%)
Gini Coefficient	G	0.172	0.379	120.35	—
	T	0.0517	0.243	369.96	100
Theil Index	T_B	0.0311	0.0521	67.52	21.40
	T_W	0.018	0.191	961.11	78.60

A similar structural pattern was observed in the dimension of actual resource allocation. Analysis of per capita procurement volume and procurement expenditure indicated a modest reduction in overall inequality at the national level in 2021 compared with 2019 (the Gini coefficient for per capita procurement volume decreased from 0.335 to 0.317, while the Theil index for procurement expenditure declined from 0.2788 to 0.2521).

Notably, within the western region, the Gini coefficient for per capita procurement volume decreased substantially from 0.311 in 2019 to 0.221 in 2021 (Table 3). Furthermore, decomposition of the Theil index in 2021 revealed that within-region disparities accounted for 86.26% of total inequality in per capita procurement volume and 77.56% in procurement expenditure, respectively (Table 4).

Table 3. Gini coefficients and temporal trends of per capita procurement volume and amount by region

Indicator	Region	$G(2019)$	$G(2021)$	No. of Provinces
Volume per capita	Overall	0.3347	0.3171	31
	Eastern	0.349	0.377	11
	Central	0.17	0.215	9
	Western	0.311	0.221	11
Amount per capita	Overall	0.3861	0.3847	31
	Eastern	0.41	0.36	11
	Central	0.205	0.312	9
	Western	0.315	0.338	11

Table 4. Theil index and spatial decomposition of national coronary stent allocation

Indicator	Year	T	$T_B(\%)$	$T_W(\%)$	Within-region Disparities		
					Eastern	Central	Western
Volume per capita	2019	0.1985	0.0465 (23.41%)	0.1520 (76.59%)	0.201	0.0467	0.1638
	2021	0.1785	0.0245 (13.74%)	0.1539 (86.26%)	0.2362	0.0731	0.0954
Amount per capita	2019	0.2788	0.0709 (25.43%)	0.2079 (74.57%)	0.2887	0.0685	0.1644
	2021	0.2521	0.0566 (22.44%)	0.1955 (77.56%)	0.2113	0.161	0.1956

Note: T denotes Overall Disparity; T_B and T_W denote Between-region and Within-region disparities, respectively. Figures in parentheses represent the percentage contribution of each

component to the overall disparity.

3.3 Spatial Autocorrelation and Evolution of Clustering Patterns

Global Moran's I tests indicated a statistically significant positive spatial autocorrelation in provincial per capita stent procurement throughout the study period, although the strength of spatial dependence weakened over time. Specifically, Moran's I decreased from 0.2996 in 2019 ($z = 4.31$, $P < 0.001$) to 0.1440 in 2021 ($z = 2.22$, $P = 0.027$), suggesting a transition toward a more spatially dispersed distribution of procurement volumes.

Local Indicators of Spatial Association (LISA) further revealed dynamic changes in spatial clustering patterns (Figure 5). In 2019, significant "high-high" (HH) clusters were primarily concentrated in North China and the eastern coastal regions, while "low-low" (LL) clusters were predominantly located in southwestern provinces. Inner Mongolia exhibited a significant "low-high" (LH) spatial outlier pattern.

By 2021, the extent of "high-high" clusters had contracted, while the range of "low-high" outliers expanded across certain northern provinces. The previously observed "low-low" clustering pattern in the southwest had dissipated. Meanwhile, Xinjiang in the northwest transitioned from a non-significant state to a significant "high-low" (HL) spatial outlier, indicating an emerging spatial divergence in that region.

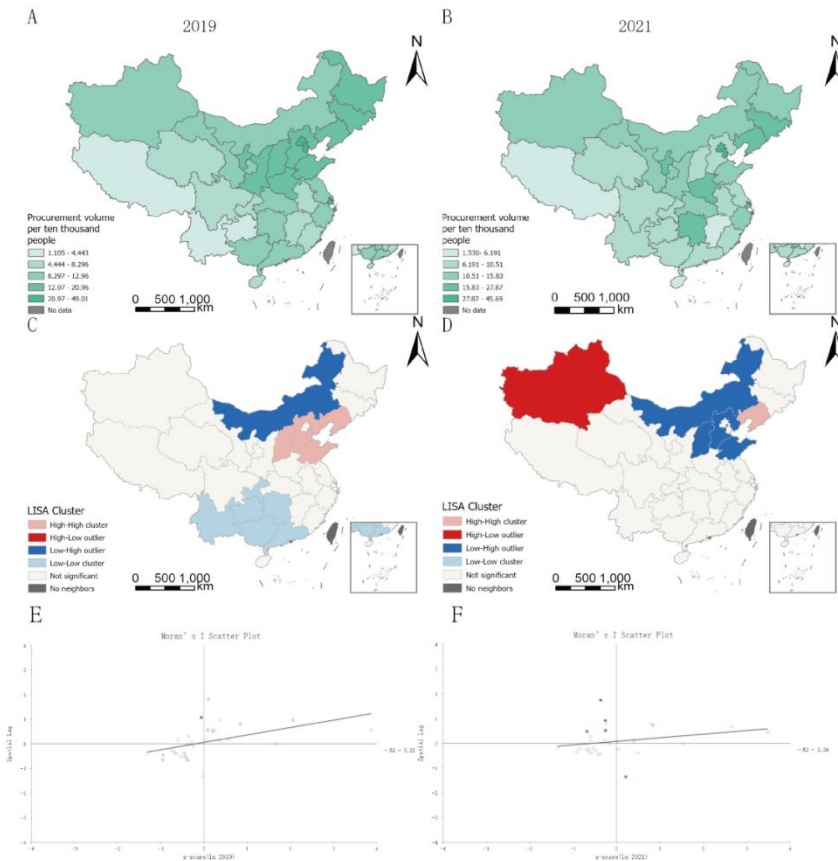


Figure 5. Spatial distribution and clustering patterns of per capita coronary stent procurement volume in China

Note:(A, B) Spatial distribution of per capita coronary stent procurement volume across Chinese provinces in 2019 and 2021. (C, D) Local Moran's I cluster maps showing the spatial clustering patterns of procurement volume.(E, F) Moran's I scatter plots for 2019 and 2021.

Note:Base map source: National Administration of Surveying, Mapping and Geoinformation of China. "Not significant" indicates provinces where the local spatial autocorrelation failed the significance test ($P < 0.05$). "No neighbors" refers to provinces excluded from the spatial weight matrix due to lack of adjacent units.

4. Discussion

This study, based on a comparative analysis of national procurement data from 2019 and 2021, found that following the implementation of the national VBP policy for

coronary stents, prices declined substantially, procurement volumes increased, and total procurement expenditures decreased markedly, with the average price of bid-winning products falling by more than 90%. This finding is consistent with prior empirical evidence based on interrupted time series (ITS) analyses^[24,25], and translated into a marked improvement in per capita affordability. More importantly, this study provides a systematic assessment of the spatial equity implications of VBP in the allocation of coronary stents in China. The results indicate that, although perfect spatial equilibrium has not yet been achieved, the policy has fundamentally reshaped the underlying structure of inequality and substantially reduced historically entrenched regional disparities. Instead, a dual pattern has emerged in the post-VBP era: a structural shift in inequality from macro-level regional disparities to micro-level intra-provincial heterogeneity, alongside the persistent influence of spatial geographic frictions.

Collectively, these findings suggest that China's governance of high-value medical consumables has undergone a critical transition—from a narrow focus on price regulation to a more complex paradigm centered on spatial equity. This transformation provides a valuable empirical benchmark for understanding large-scale resource reallocation within a unified national market.

For a long time, the high cost of medical devices has constituted a fundamental barrier to the widespread adoption of PCI in China^[5], giving rise to a classic manifestation of the Inverse Care Law—where populations in less developed regions, despite having greater clinical need, face the greatest difficulty in accessing life-saving

interventions^[26]. This study demonstrates that, following VBP implementation, the number of affordable stents per capita increased by approximately 58-fold, indicating a paradigm shift in which PCI has transitioned from an elite, resource-intensive intervention to a broadly accessible public health service^[21]. These findings also offer important international insights into price governance for high-value medical consumables. For instance, India attempted to regulate prices through price capping; however, in the absence of complementary controls over distribution and service pricing, healthcare providers often compensated by increasing ancillary service charges, limiting reductions in patients' total expenditures and leaving the risk of catastrophic health spending largely unchanged^[27]. In contrast, Japan employs a Foreign Average Price (FAP) system, dynamically adjusting reimbursement ceilings based on international reference prices, albeit with relatively gradual price reductions^[10,28]. Compared with these approaches, China's VBP model leverages centralized demand aggregation at the national level to secure substantial bargaining power, complemented by the "zero-markup" policy for medical consumables in public hospitals. This integrated mechanism has effectively eliminated excessive profit margins within the distribution chain and substantially reduced longstanding financial access barriers, particularly in central and western regions and at the primary care level^[25,29].

The decomposition of the Theil index provides critical evidence on the evolving structure of healthcare inequality in China. The findings reveal a fundamental reversal in the primary drivers of inequality: whereas inter-regional disparities dominated in

2019, intra-provincial variation emerged as the dominant source of residual inequality, indicating that the policy has effectively neutralized macro-level regional disparities and shifted the focus of governance toward within-province optimization. This structural shift suggests that, with the nationwide homogenization of prices, macro-level geographic location is no longer the dominant determinant of accessibility. Instead, consistent with prior literature, current disparities in resource allocation appear to be increasingly shaped by intra-provincial factors, including local economic capacity, catheterization laboratory infrastructure, educational attainment, and the fiscal balance of regional health insurance funds^[13,30-32]. This pattern aligns with existing evidence on equity in hospitalization expenditures for chronic diseases in China^[33,34]. These findings indicate that, once the absolute price barrier of high-value consumables is removed, the allocation of critical care resources begins to resemble that of routine healthcare services—being heavily dependent on the level of pooling in local insurance systems and the long-term capacity of primary healthcare infrastructure. This transformation reflects not only a decentralization of geographic constraints but also a broader paradigm shift in healthcare market governance. Specifically, large-scale demand aggregation within a unified national market can rapidly eliminate entrenched geographic price premiums, thereby transitioning resource allocation from a price-driven, ability-to-pay model toward a need-based model grounded in healthcare system capacity.

The significant decline in Global Moran's I indicates that the spatial distribution of stent resources is progressively breaking away from prior patterns of geographic

clustering, moving toward a more homogeneous configuration^[35,36]. LISA analysis further demonstrates that previously contiguous “low–low” clusters had largely disappeared by 2021, suggesting that the policy has effectively elevated utilization levels in historically under-resourced regions^[37,38]. Compared with other disease domains, such as dementia care, where strong spatial clustering persists ^[22], these findings highlight the substantial policy penetrance of targeted interventions for high-value medical consumables. The limited presence of residual spatial outliers in certain northwestern regions (e.g., Xinjiang) should be interpreted as reflecting structural geographic constraints rather than policy inefficacy. From the perspective of Spatial Mismatch Theory, while VBP has successfully removed major financial barriers, physical accessibility remains influenced by geographic and infrastructural factors, particularly in sparsely populated areas where time-sensitive emergency care (e.g., the 120-minute treatment window for STEMI) imposes inherent constraints^[39,40]. Overall, these findings suggest that VBP has effectively disrupted macro-level geographic clustering and established a more equitable baseline for resource distribution. Future improvements in spatial equity are therefore more likely to depend on strengthening local healthcare infrastructure and service delivery capacity, rather than further price-based interventions.

The substantial price reductions did not lead to any deterioration in the quality of clinically used consumables. On the contrary, the procurement share of high-performance cobalt–chromium–platinum alloy DES increased to nearly 99% following VBP implementation, effectively replacing traditional stainless steel stents.

This finding provides strong evidence that the policy not only removed financial barriers but also facilitated a generational upgrade in the structure of the cardiovascular interventional device market in China^[41]. Although this study does not include micro-level data on clinical practice patterns, prior empirical research suggests that reductions in device prices may be accompanied by adjustments in service utilization, such as increased use of adjunctive technologies (e.g., intravascular ultrasound, IVUS)^[21,42]. Such changes can be understood as typical system-level adaptations within healthcare delivery, reflecting shifts in cost structures rather than unintended distortions. These findings underscore the importance of complementing procurement reform with broader payment and service regulation strategies. In particular, policy efforts should extend beyond single-product price control toward a more integrated evaluation of total care pathway costs, ensuring that efficiency gains from price reductions are sustained without inducing unintended expenditure shifts^[24,41].

This study offers several important implications for global health governance. First, as macro-level regional disparities have been substantially reduced, future policy priorities should shift toward optimizing within-province implementation, including strengthening primary healthcare capacity, improving catheterization laboratory infrastructure, and enhancing the training and distribution of specialized personnel. In parallel, greater emphasis should be placed on inter-provincial policy coordination, the diffusion of best practices, and context-specific adaptation across regions with heterogeneous healthcare system capacities. Second, China's integrated model of

“demand aggregation + distribution governance” provides a valuable reference for low- and middle-income countries (LMICs) seeking to address price inflation and equity challenges in high-value medical consumables and to advance universal health coverage (UHC). Third, procurement reform should be further aligned with medical service pricing and provider payment systems (e.g., DRG/DIP) to ensure appropriate compensation for healthcare professionals, reduce reliance on consumable-based revenues, and sustain the gains in financial accessibility within a more balanced incentive structure.

Several limitations should be acknowledged. First, the analysis captures primarily the short-term effects following VBP implementation, and longer-term dynamics warrant further longitudinal investigation. Second, the use of aggregated provincial-level data may obscure heterogeneity across hospital tiers and patient socioeconomic groups. Third, the absence of micro-level clinical and cost data precludes direct assessment of changes in treatment pathways and healthcare utilization behavior.

5. Conclusions

Using national procurement data, this study demonstrates that VBP has substantially improved the accessibility of coronary stents and facilitated a generational upgrade in consumable quality. The drivers of inequality have shifted from macro-level inter-regional disparities to micro-level intra-provincial variation, accompanied by a significant attenuation of spatial clustering. These findings indicate a transition from price-driven inequality to capacity and implementation-driven heterogeneity,

highlighting the need for health governance to move beyond cost containment toward spatial equity. Future policy efforts should therefore focus on optimizing within-province implementation, strengthening primary healthcare capacity, and enhancing coordination, best-practice diffusion, and context-specific adaptation across regions.

Declarations

Ethics approval and consent to participate

Not applicable.

Competing interests

Not applicable.

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Conflict of interest

Not applicable

Availability of data and material

The data used and analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

YW, YL (Yijun Liu), and SL contributed equally to this work. YW, BJ, and ZY conceived and designed the study. YW and SL collected and curated the data. YW and YL performed the statistical analysis and interpreted the results. YW drafted the manuscript. QZ and YL (Yongqi Li) contributed to methodology development and data interpretation. BJ, BW, and ZY critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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