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Impact of an innovative case-based payment reform on hospital cost variation: insights from cerebral infarction inpatients in China

Yining Wang[1†], Shiting Liu[1†], Xinyu Zhang[2], Haifeng Ma[1] and Xiaohua Ying[1,3*]

Abstract

Background Variations in hospital costs often indicate deficiency in efficient and standardised care. Case-based provider payment systems are utilised globally to address these issues. In China, an innovative case-based payment scheme called the Diagnosis–Intervention Packet (DIP) under the global budget framework has been progressively implemented. However, evidence regarding its effectiveness and potential mechanisms underlying its impact is limited. This study aimed to investigate the impact of DIP reform on hospital cost variations among patients with cerebral infarction (CI) and to explore potential pathways through quality-cost trade-offs.

Methods This cross-sectional study analysed de-identified discharge records of patients from City G, China, between January 2018 and December 2022. The study included 293,255 cases discharged with CI from 185 hospitals. Interrupted time series models were used to assess the overall and heterogeneous impacts on hospital cost variations, measured by the coefficient of variation (CV) and interquartile range (IQR) of the hospital-level average cost per case. The contribution of each itemised cost was quantified using grey relational analysis. Quality measures were compared across hospital groups organised based on the hospitals' relative cost rankings.

Results Following the DIP reform, a significant immediate decline of 0.137 ($p = 0.031$) was observed in the CV. The quarterly trends in CV decreased by 0.001 ($p = 0.954$) and IQR by 103.40 RMB ($14.48; $p = 0.389$). Subgroup analyses found significant reductions in secondary hospitals, surgical groups, and medication costs, with medication costs aligning the most with the total change. Given hospital convergence toward the average cost level, no association between costs and quality was observed. Hospitals transitioning from the high-cost category experienced a reduction in in-hospital mortality (-0.5%). Similarly, those moving from the average- to low-cost category demonstrated decreased mortality (-0.7%) and complications (-0.5%).

Conclusions Our findings revealed a concentrated distribution of post-reform hospital costs without compromising quality. These findings suggest the effectiveness of case-based payment systems in reducing hospital cost variations and improving healthcare efficiency, potentially because providers adopt more standardised behaviours in response

†Yining Wang and Shiting Liu contributed equally.

*Correspondence:
Xiaohua Ying
xhying@fudan.edu.cn

Full list of author information is available at the end of the article

to incentive changes. This study offers insights to other countries on payment systems as leverage to achieve efficient, equitable, and high-value care.

Keywords Case-based payment scheme, Diagnosis-Intervention packet, Hospital variation, Inpatient costs, Cerebral infarction, China

Introduction

Hospital cost variation is a common issue in global health systems across various diseases. Previous studies have highlighted notable cost disparities among medical and surgical conditions, including stroke, paediatric, and cancer, in countries such as the United States (US), France, and China [1–5]. For instance, cancer surgeries such as colectomy and prostatectomy exhibited considerable variations in costs in the US [5]. In China, similar variations existed among patients with cerebral infarction (CI), a common subtype of stroke [1]. Such variation signals insufficiencies within healthcare systems, complicating cost control for insurers and increasing healthcare expenditure [3, 6]. From the perspective of patients, this can lead to unequal financial burdens and disparities in the quality of care [7, 8]. To address this issue, researchers have focused on identifying the drivers underlying cost variation and have noted that non-adherence to standardised clinical guidelines by healthcare providers was a potential cause, particularly in fee-for-service payment systems [9]. This finding prompted health authorities to implement measures to encourage compliance [10].

Case-based payment systems are widely adopted globally to control costs and regulate health provider behaviour in inpatient care [11, 12]. Similar approaches have been piloted and established in China in response to rapid increases in healthcare expenditure and significant cost variations. In January 2018, City G, one of the largest and most developed cities in Southeast China with a population of 18.8 million and a gross domestic product (GDP) per capita of ¥161.6 ($22.6) thousand in 2023, implemented the innovative Diagnosis-Intervention Packet (DIP) payment pilot program for inpatient services. This replaced the fixed-rate per admission policy with an annual cap on hospital compensation for all locally insured patients under the basic health insurance programs [13]. Following the success of the pilot program in City G for controlling costs, the DIP payment scheme has rapidly expanded nationwide, particularly in resource-limited areas, owing to its flexibility and practicality. By July 2024, China implemented the DIP model under a global budget framework in 192 regions [14].

The DIP system consists of the following key components: classification, weight scheduling, and payment mechanisms. Patients were categorised into cost-homogeneous groups using ICD-10 (International Classification of Diseases, Tenth Revision) codes for principal diagnoses and ICD-9-CM-3 (International Classification of Diseases, Ninth Revision, Clinical Modification) codes for procedures based on historical discharge data from the previous three years [15]. Each DIP group was assigned a relative weight (RW) to reflect resource consumption based on average costs per hospital admission. The exchange rate of the RW, consistent across all DIP groups, was determined ex-post by dividing the yearly regional budget by the total RW of all inpatient cases [16]. Payments for patients in each DIP group are the product of RW and the exchange rate, with adjustments for additional factors such as hospital level and quality. Therefore, hospitals may be incentivised to implement refined management practices and focus on disease groups for supervision [17]. Additionally, they may regard the average payment standards as profitability yardsticks, motivating them to adjust the average cost of each DIP group close to these standards [18–20].

Limited studies have explored the impact of provider payment reforms on cost variation, with most focusing on regional or patient-level differences [1, 21]. A US study investigated cost variations among hospital referral regions associated with different payment models and found decreased variations only after the bundled payment [21]. Similarly, a Chinese study analysed patient-level cost variations associated with the diagnosis-related group (DRG) payment, reporting reductions for patients with chronic obstructive pulmonary disease, acute myocardial infarction, and CI [1]. To the best of our knowledge, no study has examined the cost variation effects of the innovative DIP payment in China, nor has any chosen hospitals as the aggregate unit of analysis. Furthermore, the underlying mechanisms are poorly explored.

This study aimed to address the following questions: Did the DIP reform effectively reduce hospital cost variation? Did effects differ by hospital level, treatment method, and cost subtype? What are the underlying pathways? The objective was to evaluate the overall and heterogeneous impacts of the DIP payment reform on hospital-level cost variation for patients with CI in a major pilot city in Southeast China. With each hospital quarter as an observation unit, hospital-level cost variation was defined using the interquartile range (IQR) and coefficient of variation (CV) of hospital average costs. To explore the potential mechanisms, hospitals were grouped into three annual cost categories to assess the movement and associated quality changes. It offered valuable insights into the effectiveness of case-based payment reforms in narrowing hospital variation and regulating provider behaviour, thereby providing other developing countries with experiences to implement similar payment schemes.

Methods

Data sources and study population

We used the de-identified discharge records of patients in City G from 2016 to 2022. The dataset comprised case-level information on patient and hospital characteristics, admission and discharge statuses, diagnoses, procedures, and inpatient costs.

The study population included basic medical insurance beneficiaries with a principal discharge diagnosis of CI between 1 January 2016 and 31 December 2022, identified using ICD-10 code I63. As the most common subtype of stroke, CI imposes a significant societal burden worldwide in terms of morbidity and healthcare costs. It is prevalent among older adults, representing the second largest inpatient volume, accounting for 4.65% of the cases in our sample. These patients tend to incur high costs, with considerable cost variations observed in China [1, 22]. Furthermore, as CI and its complications result in increased risks of disability and death without timely care, it is closely monitored by national health authorities for quality control, warranting close attention to service quality [23]. Patients were excluded if their costs were paid per diem or if demographic or cost information was missing. To eliminate potentially erroneous data, we excluded patients with observed costs in the bottom or top 1% of the distribution [24, 25]. Lastly, to increase the statistical reliability of our estimates, we excluded hospitals with fewer than 50 annual cases [3, 26].

Outcomes and measures

We selected hospitals as the aggregate unit of analysis using the interquartile range (IQR) and coefficient of variation (CV) as primary outcomes, with higher values indicating greater variation. To obtain these outcomes, we first adjusted the individual costs of inflation using the consumer price index in City G to standardise them to 2022. Subsequently, a case-mix adjustment was performed on log-transformed costs using linear regression with random hospital effects to account for the clustering of patients within hospitals [5]. We adjusted for patients' demographic and clinical features, including age, sex, medical insurance type, and disease severity [12, 27, 28]. Severity was measured using the Charlson Comorbidity Index based on comorbidities, with I63 omitted from the cerebrovascular accident upon calculation [29]. Adjusted individual costs were then aggregated as the average costs at the hospital level, with each hospital per quarter serving as a single observation unit. IQR was calculated as the difference between the 75th and 25th percentiles based on the distribution of hospital costs, and CV was defined as the ratio of the standard deviation (SD) to the mean.

For the mechanism analysis, we included two quality variables, in-hospital mortality and complications, to investigate the quality-cost trade-off. In-hospital mortality was defined as death during admission and was obtained from the discharge status. In-hospital complications were defined as nonneurologic complications requiring intervention and were calculated based on ICD-10 codes for secondary diagnoses. Complications of interest were identified from previous studies, and further details are provided in Table S1 in Additional file 1 [30–32]. These indicators were reported as overall rates and also risk-adjusted using a mixed-effects logistic regression model, incorporating the same covariates as those used for cost adjustments [25].

Statistical analysis

We used interrupted time-series analysis (ITSA), a robust quasi-experimental method, to assess the impact of the DIP reform on hospital cost variations. The time interval was measured in quarters, and the equation used is as follows:

$$Y_q = \beta_0 + \beta_1 T_q + \beta_2 DIP_q + \beta_3 DIP_q T_q + \beta_4 X_q + \epsilon_q \quad (1)$$

where Y_q is the outcome variable measured at each quarter q; T_q is the time series value of 28 quarters; DIP_q is a dummy variable valued at zero during the pre-reform period from 2016 Q1 to 2017 Q4, and one during the post-reform period from 2018 Q1 to 2022 Q4; X_q is a dummy variable for each quarter to control for seasonality. β_0 represents the baseline level of the outcome variable; β_1 denotes the slope of the outcome variable before the DIP reform; while β_2 and β_3 indicate the immediate level change and trend change following the intervention, respectively. We fitted a Prais-Winsten estimation with the Durbin-Watson statistics to address autocorrelation [33, 34].

To explore heterogeneous effects, we conducted three subgroup analyses. First, we performed separate analyses in the tertiary and secondary hospitals. Second, we categorised the patients into surgical (those undergoing at least one procedure) and medical (those receiving conservative treatments) groups based on procedure codes and applied our model accordingly. This classification aimed to determine whether the effects varied across treatment strategies and resource use patterns, with the hypothesis that the surgical group would show more improvement due to greater treatment discrepancies and larger baseline variations. Finally, we examined different cost components, including medication and consumables. These two cost subtypes warrant significant policy attention due to previous irrational incentive systems and hospitals' potential for manipulation, accounting for large proportions of total costs. We used grey relational analysis (GRA) to quantify the contribution of each cost component to the total change [35].

For mechanism analysis, we grouped hospitals into high-(> 75th percentile), average (25-75th percentile), and low-cost (< 25th percentile) categories based on annual cost quartiles. We examined whether hospitals transitioned between categories and trade-off costs by quality in response to the reform.

We performed four sensitivity analyses. First, we included patients in the bottom or top 1% of the distribution. We then accounted for COVID-19 by introducing an additional breakpoint in the ITSA and a volume-based procurement policy by analysing other costs unrelated to medications and consumables. Other costs included therapy costs, diagnostic costs, bed fees, blood product fees, and costs of other services. Finally, we used generalised linear mixed models (GLMM) with a log link and random hospital effects in the gamma distribution to confirm the robustness of our case-mix adjustment [24, 28]. All data cleaning and analyses were performed using Stata MP, version 17.0 (StataCorp LLC) with 2-sided $p < 0.05$ considered statistically significant.

Results

Sample characteristics

This study included 293,255 patient records from 185 hospitals. Among them, the mean (SD) age was 70.1 (12.5) years, and 57.5% were male. Table 1 summarises the characteristics of the study sample before and after the reform. A total of 64,615 hospitalisations from 91 institutions before the DIP reform were included, accounting for 3.8% of total cases, with mean (SD) age of 69.8 (12.2) years and 59.4% of males. A total of 228,640 hospitalisations from 175 institutions were included after the DIP introduction, accounting for 5.0% of total cases, with the mean (SD) age of 70.2 (12.5) years and 56.9% males. The adjusted average cost per case slightly decreased from a mean (SD) of 22,263.3 (19,343.6) RMB pre-reform to 21,310.6 (18,571.2) RMB post-reform. Regarding outcome variables, the adjusted CV of hospital-level average costs before and after the DIP reform was 0.09 and 0.12, respectively, while the adjusted IQR was 2,298.5 RMB and 3,296.3 RMB.

Overall impacts of the DIP reform on hospital cost variation

Figure 1 presents the time-series analyses of the outcome variables. In the adjusted CV, the introduction of DIP

Table 1 Sample characteristics of patients with cerebral infarction

	Before DIP reform (2016–2017)	After DIP reform (2018–2022)
Hospital Characteristics		
No. of hospitals	91	175
Level, No. (%)		
Tertiary	53 (58.2)	78 (44.6) [a]
Secondary	28 (30.8)	68 (38.9) [a]
Primary	10 (11.0)	35 (20.0) [a]
Patient Characteristics		
No. of inpatient cases	64,615	228,640
Age (years), mean (SD)	69.8 (12.2)	70.2 (12.5)
Sex, No. (%)		
Male	38,348 (59.4)	130,166 (56.9)
Female	26,267 (40.6)	98,474 (43.1)
Insurance type, No. (%)		
UEBMI	43,638 (67.5)	154,643 (67.6)
URRBMI	20,977 (32.5)	73,997 (32.4)
Treatment, No. (%)		
Surgical	6,281 (9.7)	60,616 (26.5)
Medical	58,334 (90.3)	168,024 (73.5)
Charlson Comorbidity Index, mean (SD)	1.4 (1.2)	1.6 (1.3)
Adjusted total cost per case [b] (RMB [c]), mean (SD)	22,263.3 (19,343.6)	21,310.6 (18,571.2)
Outcome measures		
Adjusted coefficient of variation [b]	0.09	0.12
Adjusted interquartile range [b] (RMB [c])	2,298.5	3,296.3

DIP Diagnosis-Intervention Packet, *SD* standard deviation, *UEBMI* urban employee basic medical insurance, *URRBMI* urban and rural residence basic medical insurance

[a] The sum of the number of hospitals in different categories after the reform exceeded the total number because the level of each hospital may change over time

[b] Costs accounting for inflation and case-mix adjustment using linear regression

[c] 1 RMB is equal to 0.14 USD

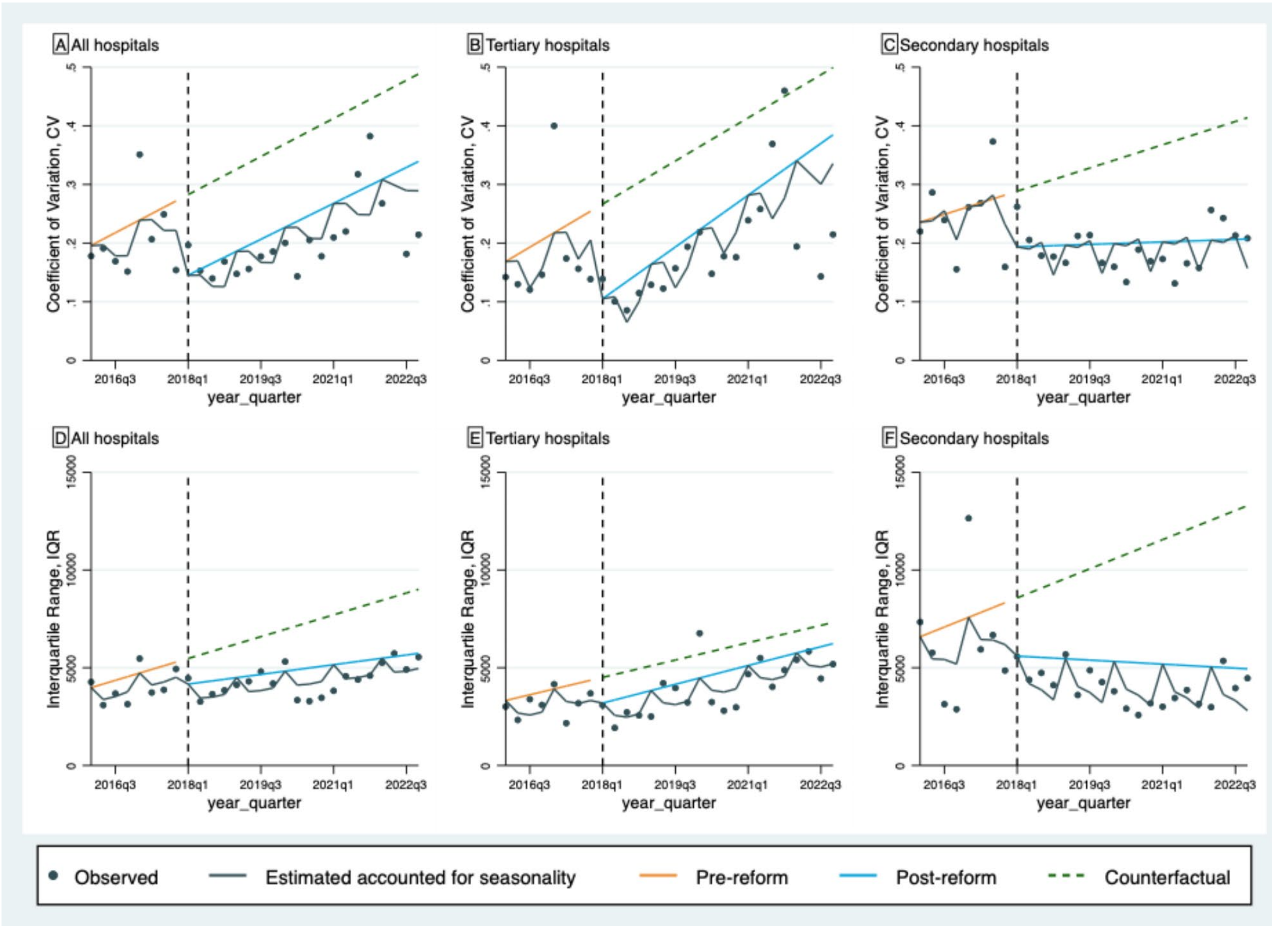

Fig. 1 Quarterly trends in adjusted CV and IQR among patients with cerebral infarction. *CV* coefficient of variation, *IQR* interquartile range. *Note* The vertical dashed black line depicts the start of the reform in Q1, 2018. To illustrate the pre-reform, post-reform, and counterfactual trends as smooth lines, we applied the interrupted regression results without dummies for the season

was associated with a significant immediate reduction of 0.137 (95% CI, 0.014 to 0.261; $p = 0.031$) and a slope decrease of 0.001 (95% CI, -0.021 to 0.022; $p = 0.954$) per quarter. We found an immediate reduction of 1,310.2 RMB (95% CI, -53.6 to 2,674.1 RMB; $p = 0.059$) and a slope decrease of 103.4 RMB (95% CI, -141.3 to 348.1 RMB; $p = 0.389$) per quarter in the adjusted IQR following the payment change.

Heterogeneous impacts of the DIP reform on hospital cost variation

The results of the subgroup analysis are shown in Fig. 1; Table 2. In the adjusted CV, the implementation of DIP payments resulted in significant immediate reductions of 0.095 (95% CI, 0.009 to 0.181; $p = 0.032$) in secondary hospitals and 0.161 (95% CI, 0.003 to 0.320; $p = 0.046$) in tertiary hospitals, as well as a quarterly slope decrease of 0.006 (95% CI, -0.009 to 0.021; $p = 0.427$) in secondary hospitals. In adjusted IQR, we found immediate reductions in both hospital levels and a 282.8 RMB (95% CI, -242.2 to 807.9 RMB; $p = 0.275$) slope decrease per quarter in secondary hospitals post-reform.

By stratification of treatment methods, the DIP reform was associated with non-significant immediate reductions in adjusted CV in both the surgical and medical groups following the reform, with the surgical group demonstrating a quarterly slope decrease of 0.012 (95% CI, -0.024 to 0.049; $p = 0.489$). However, the adjusted CV increased modestly by 0.008 (95% CI, -0.011 to 0.027; $p = 0.388$) after the payment change. The IQR exhibited similar patterns. We additionally found significant effects in slope changes in the surgical group in secondary hospitals (3,654.7 RMB; 95% CI, -942.9 to 8,252.3 RMB; $p = 0.113$).

When stratified by cost component, the DIP reform was associated with an overall nonsignificant immediate reduction of 0.031 (95% CI, -0.168 to 0.230; $p = 0.750$) and a quarterly slope decrease of 0.000 (95% CI, -0.040 to 0.041; $p = 0.983$) per quarter in the adjusted CV of medication costs, with corresponding values of 0.147 (95% CI, -0.203 to 0.497; $p = 0.393$) and 0.002 (95% CI, -0.059

Table 2 Changes in levels and quarterly trends for adjusted CV and IQR in subgroups

	All hospitals, coefficient (95% CI)		Tertiary hospitals, coefficient (95% CI)		Secondary hospitals, coefficient (95% CI)	
	Step change	**Slope change**	**Step change**	**Slope change**	**Step change**	**Slope change**
Pannel A: CV						
Treatment Method						
Surgical	-0.101 (-0.300, 0.097)	-0.012 (-0.049, 0.024)	-0.045 (-0.232, 0.142)	0.006 (-0.027, 0.039)	-0.054 (-0.383, 0.275)	0.003 (-0.056, 0.061)
Medical	-0.022 (-0.121, 0.076)	0.008 (-0.011, 0.027)	-0.062 (-0.217, 0.093)	0.004 (-0.025, 0.032)	-0.041 (-0.120, 0.038)	0.005 (-0.009, 0.018)
Itemized cost						
Medication cost	-0.031 (-0.230, 0.168)	0.000 (-0.041, 0.040)	-0.062 (-0.356, 0.232)	0.006 (-0.050, 0.061)	-0.001 (-0.109, 0.106)	-0.003 (-0.022, 0.016)
Consumable cost	-0.147 (-0.497, 0.203)	-0.002 (-0.064, 0.059)	0.037 (-0.371, 0.445)	0.013 (-0.062, 0.088)	-0.856 (-1.566, -0.146)*	-0.033 (-0.158, 0.092)
Pannel B: IQR, RMB						
Treatment Method						
Surgical	-1,439.0 (-8,471.9, 5,593.8)	3.3 (-1,234.8, 1,241.3)	-3,437.6 (-9,585.7, 2,710.4)	-407.5 (-1,486.0, 671.0)	-28,235.4 (-54,390.6, -20,80.2)*	-3,654.7 (-8,252.3, 942.9)
Medical	-119.5 (-1,221.2, 982.2)	230.0 (27.2, 432.9) [b]	-236.7 (-1,351.6, 878.3)	105.2 (-97.2, 307.7)	-1,025.2 (-4,457.1, 2,406.6)	252.1 (-350.1, 854.4)
Itemized cost						
Medication cost	-877.4 (-1,435.5, -319.3)**	-122.5 (-220.4, -24.5)*	-595.4 (-1,269.7, 79.0)	-118.0 (-236.3, 0.3)	-1,401.2 (-3,174.9, 372.5)	-76.1 (-399.9, 247.7)
Consumable cost	-263.9 (-1,600.8, 1,073.0)	104.1 (-214.4, 422.6)	-870.9 (-2,294.2, 552.5)	141.2 (-141.1, 423.6)	-90.6 (-286.0, 104.9)	1.9 (-38.8, 42.6)

CV coefficient of variation, *IQR* interquartile range, *CI* confidence interval

** $p < 0.01$, * $p < 0.05$

Note Individual costs were adjusted for inflation and case mix. The interrupted time-series analysis fitted the Prais-Winsten estimation with the Durbin-Watson statistics to address autocorrelation analyses, controlling for seasonality, and using robust standard errors

to 0.064; $p = 0.935$) for consumable costs. Significant immediate declines (95% CI, -1.566 to -0.146; $p = 0.021$) were identified in secondary hospitals. In adjusted IQR of medication costs, we found a significant immediate reduction of 877.4 RMB (95% CI, 319.3 to 1435.5 RMB; $p = 0.004$) and a slope decrease of 122.5 RMB (95% CI, 24.5 to 220.4 RMB; $p = 0.017$) per quarter after the reform. In the adjusted IQR of consumable costs, a quarterly slope increase of 104.1 RMB (95% CI, -422.6 to 214.4 RMB; $p = 0.504$) was observed post-reform. The GRA model demonstrated that medication costs displayed a stronger correlation (0.544) with total costs than with consumable costs (0.474), consistent with the results stratified by hospital level.

Mechanism analysis

Figure 2 illustrates the dynamic changes in the hospital cost categories between 2016, 2019, and 2022, indicating a noticeable trend toward convergence. The thresholds defining the cost categories remained robust across these years, indicating that hospital transitions occurred as absolute average costs changed. Of the 35 hospitals present in the dataset across all three years, 66.7% moved from the high-cost group in 2016 to the average- or low-cost category in 2019, while 66.7% in the low-cost group shifted upward (Table 3).

We further examined service quality and found that hospitals generally experienced lower mortality rates but higher complication levels in 2019 than in 2016 (Table 3). In-hospital mortality decreased from 1.1% (95% CI, 0.8 to 1.3%) in 2016 to 0.7% (95% CI, 0.5 to 0.8%) in 2019, while in-hospital complications rose from 4.8% (95% CI, 4.4 to 5.3%) to 5.4% (95% CI, 5.1 to 5.8%). Hospitals transitioning out of the high-cost category demonstrated an improvement in in-hospital mortality (-0.5%) but a deterioration in complications (0.9%). Hospitals moving from the average- to low-cost category showed improvements in both mortality (-0.7%) and complications (-0.5%). Conversely, hospitals moving upward from either the low- or average-cost categories had increased complications, with varied results for mortality changes.

Sensitivity analyses

The directions and significance of the coefficients in all indicators were largely consistent when incorporating extreme values in the distribution and considering COVID-19 using a multi-phase ITSA analysis with a

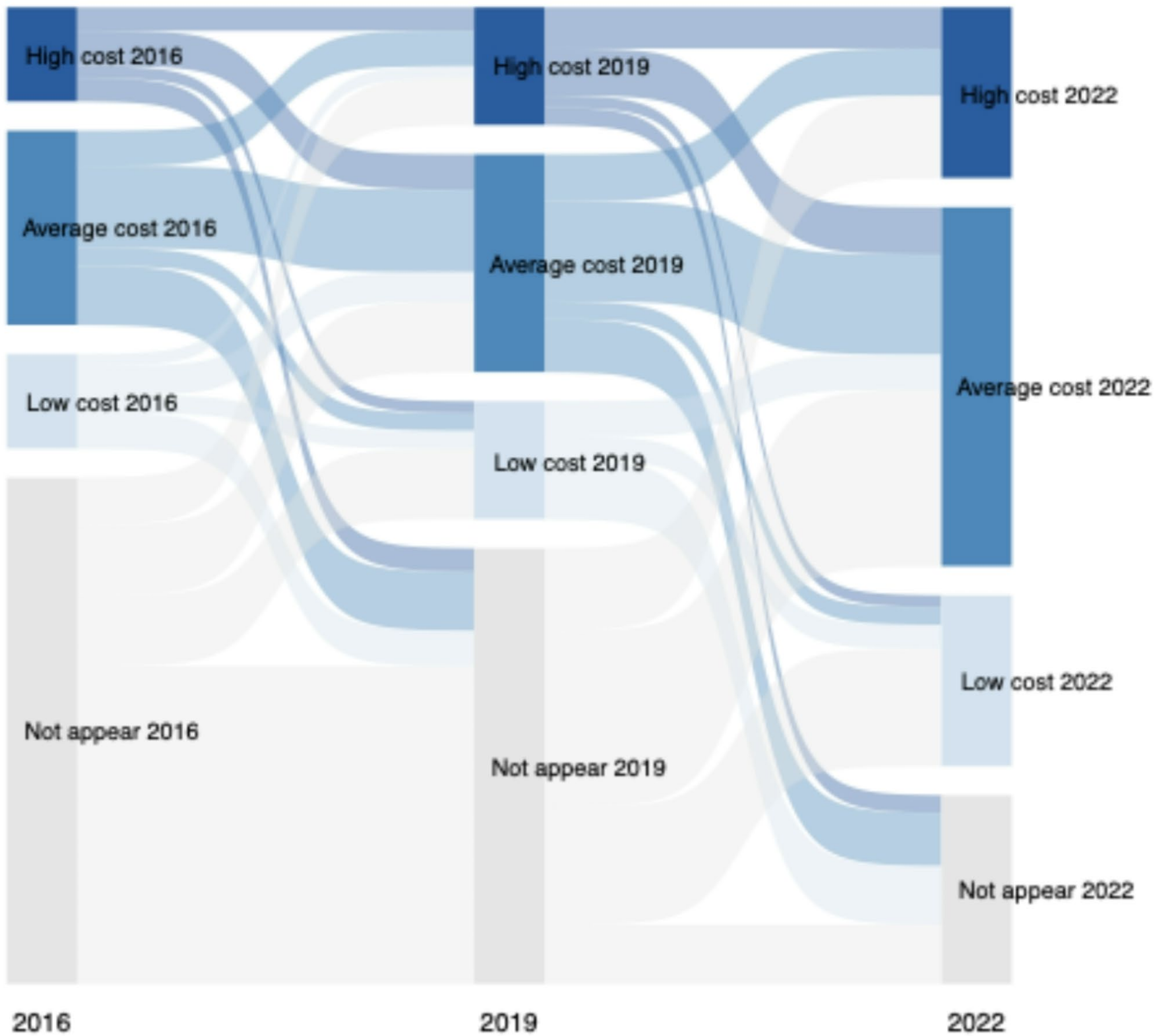

Fig. 2 Sankey diagram of transitions between cost categories among all hospital

Table 3 Transitions between cost categories and corresponding quality among 35 hospitals

	Change by category, *N* (%)	In-hospital mortality, % (95% CI)			In-hospital complication, % (95% CI)		
		2016	2019	Δ	2016	2019	Δ
High Cost	9						
No change	3 (33.3)	0.6 (-0.4, 1.5)	0.5 (0.1, 0.8)	-0.1	5.1 (2.8, 7.5)	4.9 (3.3, 6.4)	-03
Declined	6 (66.7)	1.2 (0.3, 2.2)	0.7 (0.3, 1.2)	-0.5	4.5 (3.7, 5.4)	5.4 (4.2, 6.6)	0.9
Average Cost	17						
Improved	5 (29.4)	1.3 (0.7, 1.9)	0.7 (0.4, 1.0)	-0.6	4.7 (3.6, 5.8)	5.8 (4.9, 6.7)	1.1
No change	11 (64.7)	1.1 (0.8, 1.3)	0.7 (0.4, 1.0)	-0.4	4.6 (3.7, 5.5)	5.6 (4.9, 6.3)	1.0
Declined	1 (5.6)	1.5 (0.3, 2.7)	0.8 (0.2, 1.4)	-0.7	5.6 (3.7, 7.4)	5.1 (4.5, 5.7)	-05
Low Cost	9						
Improved	6 (66.7)	0.4 (0.0, 0.8)	0.6 (0.2, 0.9)	0.2	4.7 (3.4, 6.0)	5.2 (4.2, 6.1)	0.5
No change	3 (33.3)	1.0 (0.4, 1.5)	0.5 (0.2, 0.8)	-0.4	5.7 (4.2, 7.4)	5.6 (4.9, 6.3)	-02
Overall	35	1.1 (0.8, 1.3)	0.7 (0.5, 0.8)	-0.4	4.8 (4.4, 5.3)	5.4 (5.1, 5.8)	0.6

CI confidence interval

second breakpoint in Q1 2020 (Tables S2–S4 in Supplementary material 1).

The robustness of the results was also confirmed through unadjusted and GLMM-adjusted costs, as well as other costs (total costs minus consumables and drugs) in the basic regression model (Tables S5 and S6 in Supplementary material 1). These findings remain robust in the two-breakpoint model (Tables S7–S12 in Supplementary material 1).

Discussion

This study holds significance in the context of the extensive implementation of payment reforms as leverage to reduce hospital variations and achieve health equity worldwide. Following DIP payment under the global budget in City G, we found a significant immediate reduction in hospital cost variation among patients with cerebral infarction, with a nonsignificant slope decrease. Notably, significant reductions were observed in the secondary hospitals and surgical groups. Regarding itemized costs, medication costs contributed the most to the total change. These results remain robust after accounting for concurrent events and employing different case-mix adjustment methods. Furthermore, hospitals converged toward the average-cost category. As in-hospital mortality generally decreased after the reform, hospitals did not incur expenditures at the expense of quality. These findings suggest that DIP payment enhanced efficiency by reducing hospital cost variation while maintaining quality. This effect could be attributed to providers implementing more standardised practices to align with profitability benchmarks.

Previous global studies have predominantly examined the effects of payment reforms on geographic variations in medical spending, particularly at the hospital referral region level in US [36–38]. We further extended our analysis to a more granular level by selecting hospitals as the unit of analysis, positing that variations in hospital medical practices affect cost differences, even after controlling for patient demographics and health status [25, 27]. Our findings indicate that the DIP reform in City G was associated with an immediate reduction in hospital-level adjusted CV among patients with CI. The long-term trend also decreased, as shown by the non-significant slope changes in both CV and IQR. This lack of significance may be partly attributable to our small sample size, as we had only one outcome variable per time series. This constraint limited the variation in the independent variables and increased the standard error of the regression coefficient. Nonetheless, the overall trend is consistent with previous studies on other payment schemes, such as DRG and bundled payments, verifying that prospective payment systems are effective in narrowing cost differences and enhancing provider efficiency [1, 21]. These insights have valuable implications for informing future policy developments and guiding provider behaviour. In regions facing similar challenges of controlling hospital variations and promoting care efficiency, case-based payments could serve as effective levers. Furthermore, since the DIP system has shown results comparable to other schemes, it could be extended to various developing countries due to its advantages in terms of dynamic grouping, design simplicity, and ease of implementation [39].

The convergence of hospital costs toward payment standards in the post-reform period may explain the observed reduction. Hospitals with costs above the market average face a limit below their historical expenditures and vice versa [20]. Thus, hospitals were incentivised to reduce inefficiency-related differences, possibly by decreasing avoidable medical services or transferring eligible patients to post-stroke primary care [40, 41]. Consequently, patients would receive more standardised and continuous care, enhancing health system efficiency. Secondary hospitals exhibited stronger responses, likely because of greater pre-reform inefficiency, while tertiary hospitals displayed more homogeneous baseline levels, as illustrated in Fig. 1 [42]. In addition, secondary hospitals are motivated to align their costs with payment standards to maintain profitability and competitiveness in the market [16, 43].

Subgroup analysis demonstrated varying results. We found that immediate reductions and quarterly slopes decreased in the surgical group after the DIP reform. It is possible that hospitals were previously incentivised to overuse expensive thrombolytic treatments and extend the length of stay unnecessarily for surgical patients, given that these were significant cost drivers [32, 44]. However, the DIP reform encouraged hospitals to implement clearer clinical pathways for procedures, thereby effectively reducing costs [45, 46]. Regarding itemised costs, medication costs contributed the most to reducing the variations. The previous incentive system led to the widespread overprescription of drugs, as seen in the frequent use of neuroprotectants (e.g. edaravone and ganglioside) and traditional Chinese medicine [22, 47, 48]. This reform prompted hospitals to modify their prescription practices and achieve cost homogeneity [15]. In the sensitivity analyses, we found the results to be quite robust, even when accounting for COVID-19. These findings aligned with previous studies indicating a moderate overall impact of COVID-19 on cost and quality indicators for patients with stroke or CI [49–51]. It may be attributed to hospitals' maintenance of quality standards during the pandemic and the nature of the disease, which necessitates acute therapies [52].

Our mechanism analysis confirmed that hospitals tended toward the average-cost category following the reform, resulting in a more concentrated distribution of hospital costs. To further investigate the drivers, we examined the potential quality-cost trade-off using in-hospital mortality and complications as measures. We found a general decrease in in-hospital mortality between 2016 and 2019, suggesting substantial quality improvements and significant inefficiencies before the reform. However, increased complications likely resulted from hospitals' greater emphasis on coding practices and strategic provider behaviours, such as upcoding, as the average secondary diagnoses per case in our dataset rose from 5.06 in 2016 to 7.04 in 2022 [34, 53]. Previous studies suggest a U-shaped association between costs and quality, indicating that at low quality levels, there may be a cost-saving potential for quality improvements, as observed in hospitals declining from high- or average-cost categories [54]. This implies that these hospitals were incentivised to reduce expenditures without harming quality; thus, no clear quality-cost trade-off was observed [55, 56]. It further confirmed the effectiveness of the DIP system and its value for implementation in a global context. Hospitals moving to higher-cost categories showed mixed results. The decrease in mortality might be attributed to extensive resource use for patients close to death, often described as 'red herring' [57]. Conversely, an increase in mortality and complications may reflect changes in patient severity that were not adequately captured by our case-mix adjustments [54].

Our study had several limitations. First, our focus on patients with CI and the DIP reform in City G may limit the generalisability of our findings to other patient groups or regions. Future research should assess DIP reform policies across Chinese cities and their impact on various diseases. Second, despite including comprehensive CI inpatients, the data had limitations, as specific quality indicators, such as readmission rates, were inaccessible. Third, changes in coding practices may have affected the observed complications. Nonetheless, because we compared the relative quality changes, this influence was likely negligible. Finally, we only conducted a preliminary mechanism analysis, suggesting future explorations of additional plausible pathways.

Conclusion

This cross-sectional study found a significant immediate decrease in the CV of hospital costs following the DIP reform, coupled with slope decreases in the CV and IQR, although the difference was not statistically significant. This reduction in variation was achieved without compromising the quality. These findings suggest that case-based payment systems can effectively reduce variations in hospital costs and improve service delivery efficiency. It provides other countries with experience in using payment systems as leverage to regulate provider behaviour and promote high-value care.

Abbreviations

CI	Cerebral Infarction
CV	Coefficient of Variation
DIP	Diagnosis–Intervention Packet
DRG	Diagnosis-Related Group
GDP	Gross Domestic Product
GLMM	Generalised Linear Mixed Model
GRA	Grey Relational Analysis
IQR	Interquartile Range
ITSA	Interrupted Time-series Analysis
RW	Relative Weight
SD	Standard Deviation

Supplementary Information

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Supplementary Material 1

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Author contributions

XY, XZ, YW, and SL contributed to the conception and design of the work. YW and SL performed the analysis and interpretation of the data, and drafted the work. XY and HM provided substantial review and editing for content. All authors have reviewed and agreed to the final version of the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The institutional review board of the School of Public Health, Fudan University approved this study (IRB#2020-TYSQ-03-20) and waived informed patient consent owing to the use of deidentified data. The research process complies with the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]School of Public Health, Fudan University, Shanghai, China
[2]Global Health Research Center, Duke Kunshan University, Kunshan, China
[3]Key Laboratory of Health Technology Assessment (Fudan University), Ministry of Health, Shanghai, China

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