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Does the reduction in obstetric hospitals result in an unintended decreased in-hospital delivery utilisation? A causal multilevel analysis in China

Nan Chen ,[1,2,3,4] Peter C Coyte,[5] Jay Pan [1,2]

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For numbered affiliations see end of article.

Correspondence to
Dr Jay Pan;
panjie.jay@scu.edu.cn

ABSTRACT

Introduction China's progress towards achieving Sustainable Development Goals for maternal health is largely attributed to a reduction in maternal mortality rates, driven by increased in-hospital delivery services utilisation. However, recent reductions in the number of obstetric hospitals have raised concerns about compromised access to these services. This study investigates the impact of reduced obstetric hospitals on spatial accessibility and the utilisation of in-hospital delivery services.

Methods Data from 2016 to 2020 were collected from a densely populated province with approximately 83 million residents. Directed Acyclic Graph was applied to identify a minimally sufficient set of confounders, including residential characteristics and transportation-related factors. Multilevel regression models were employed to analyse the causal effects, with sensitivity analysis using fixed effect and quantile regression models.

Results Between 2017 and 2020, the number of obstetric hospitals decreased by 21.3% (from 1209 to 951), leading to a decline in the proportion of pregnant women covered within a 2-hour driving radius (from 97.4% to 97.1%) and an increase in the maximum of shortest driving time within county (from 117.2 to 121.0 min). Multilevel regression models, adjusted for confounders, showed that a 1 percentage point increase in the proportion of pregnant women covered within a 2-hour driving radius was associated with a 13 percentage point (95% CI: 11.4 to 14.7) increase in in-hospital delivery rates, especially in areas with lower coverage and in-hospital delivery rates.

Conclusions The reduction in obstetric hospitals increased travel distances, negatively impacting in-hospital delivery utilisation. Expanding the proportion of pregnant women covered within a 2-hour driving radius may be more effective than reducing the maximum of shortest travel distance within a county when optimising obstetric hospital locations. These findings provide insights for optimising obstetric facility locations in similar low- and middle-income countries. While improving spatial accessibility is important, the potential quality gains from centralising obstetric resources should also be considered.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Low- and middle-income countries (LMICs) focus on increasing the number of obstetric hospitals, whereas high-income countries (HICs) are reducing them.
⇒ Evidence from HICs on the impact of reducing obstetric hospitals on geographical accessibility is mixed.
⇒ In China, declining birth rates have led to a reduction in the number of obstetric hospitals, raising geographical accessibility concerns.

WHAT THIS STUDY ADDS

⇒ To our best knowledge, this would be the first study to describe the impact of reducing obstetric hospitals on both the distance to and utilisation of in-hospital delivery services in LMICs.
⇒ Using Directed Acyclic Graphs, our multilevel regression model identifies the causal effect of distance on in-hospital delivery rates.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Increasing the proportion of pregnant women covered by obstetric services is critical for maintaining the utilisation of in-hospital delivery services.
⇒ Policymakers should prioritise geographic accessibility when allocating obstetric resources, particularly in economically disadvantaged counties with lower in-hospital delivery rates.
⇒ This study provides updated evidence on the impact of hospital accessibility on in-hospital delivery rates, which highlights the continued importance of spatial accessibility in obstetric services, particularly in LMICs facing declining birth rates.

INTRODUCTION

Maternal health represents a useful metric for societal well-being and is prominent in global initiatives, such as the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs). It also forms a cornerstone of national agendas such as China's 'Healthy China 2030' plan.[1] China's remarkable strides in reducing maternal mortality, placing it among the countries with the most significant progress in achieving MDGs, have led to the early attainment of the SDGs' 'Survival' goal for maternal health and have advanced progress toward the 'Thrive' goal.[1–3] Souza *et al*'s Obstetric Transition Theory outlines five stages in the evolution of fertility patterns. This theory positions China in the fourth stage, characterised by low maternal mortality and birth rates.[1 4] This alignment suggests a trajectory towards improved maternal health outcomes and ongoing reductions in the Chinese birth rate.

Various studies have emphasised a significant correlation between declining childbirth numbers and a subsequent reduction in the number of obstetric hospitals.[5–7] This trend, driven by cost-saving motives, particularly impacts remote regions where more obstetric hospitals face closure.[7 8] For instance, Finland saw a decline in the number of obstetric hospitals from 42 to 22 over the period of 1999 to 2019,[9] while the USA observed 179 rural areas ceasing in-hospital delivery services between 2004 and 2014[8] and Japan and South Korea experienced similar reductions, aggravated by severe staff shortages in remote areas.[6 10] Studies conducted in these countries have explored the impact of reduced obstetric hospitals on distance. While some studies suggest a significant compromise in distance,[9 10] others indicate that the reduction may not have as pronounced an effect.[7 11] In this study, 'obstetric hospitals' refer to all healthcare facilities that provide obstetric services, including general hospitals with obstetrics departments and specialised obstetric hospitals.

China's total number of births declined by approximately 10% from 2016 to 2020,[12] with Sichuan Province experiencing a peak in births in 2017 followed by a gradual decline thereafter.[13] Consequently, the province saw a 20% reduction in obstetric hospitals between 2017 and 2020.[14] This decline potentially heightens the distance between pregnant women and obstetric hospitals, posing challenges to the utilisation of in-hospital delivery services. In countries like China where birth rates have significantly declined in recent years, many scholars have not paid much attention to the reduction of obstetric hospitals and its potential impact on pregnant women and the distance between them and the nearest obstetric facility. According to World Bank data, as a rapidly developing middle-income country, China's gross domestic product (GDP) per capita increased by 20% over 5 years, from US$8094 in 2016 to US$10 408 in 2020.[15] Meanwhile, Sichuan Province experienced a 44% increase in per capita GDP, rising from US$5641 to US$8137.[16] During this period, there have been significant improvements in the country's infrastructure, transportation and people's living standards. Some studies indicate that the impact of distance on the rate of in-hospital births is decreasing.[17 18] The bypassing behaviour seen in pregnant women from other countries naturally raises doubts about how much of an impact distance might have on the rate of in-hospital births in China today.[19 20]

The remarkable increase in in-hospital delivery rates has played a pivotal role in China's substantial and rapid decline in maternal mortality.[2 21] The maternal mortality ratio has declined from 88.8 cases per 100 000 births in 1990 to 18.3 cases in 2019, meanwhile the in-hospital delivery rate grew from 60.7% in 1996 to nearly 100% by 2013.[22] The Chinese government implemented many policies to increase the use of in-hospital delivery services. The highly acclaimed 'Reducing Maternal Mortality and Eliminating Neonatal Tetanus' project (2000–2013) significantly increased in-hospital delivery rates through community mobilisation, institutional capacity building and fee reductions.[23] It contributed to a 50% reduction in maternal mortality in intervention areas and was later integrated into national public health programmes.[1] China's National Health Commission has included maternal health management in the primary public health service package, enabling community health service centres to provide free maternal health management and checks, thereby increasing the willingness of mothers to use in-hospital delivery services.[23] The in-hospital delivery subsidy programme specifically for rural pregnant women has greatly improved the financial accessibility of in-hospital delivery services, financially incentivising rural pregnant women to use in-hospital delivery services.[1 24 25] One distinctive aspect of China is that home delivery is not currently supported within the framework of the Chinese healthcare system, emphasising the significance of in-hospital delivery for ensuring safe childbirth.[26] Unlike in other countries, Chinese midwives no longer offer home delivery services; instead, they focus on facilitating referrals to obstetric hospitals and assisting with childbirth in those settings.[2] However, pregnant women may still use home delivery in remote geographic locations and in ethnic minority inhabited areas.[27 28] The reduction in the number of hospitals may impede the use of in-hospital delivery services by increasing distance.

The objectives of this study are threefold: (1) to investigate the changes in the number of obstetric hospitals and the concurrent variations in distance between pregnant women and hospitals using population distribution data, birth rate estimates, geolocated hospital data and road network information; (2) to assess the causal impact of the distance to the nearest obstetric hospital on the utilisation rate of in-hospital delivery services through multilevel regression models adjusted for confounders identified via a Directed Acyclic Graph (DAG); and (3) to provide insights for optimising the location of obstetric hospitals. The manuscript is organised as follows: the next section describes the data and methods used to assess the primary research question; this is followed by the study findings and then the results are placed in the broader context of the literature, and we end with a brief conclusion.

METHODS

Study area

Sichuan Province, located in Southwest China, has a population of 83 million residents.[29 30] The province exhibits considerable geographic and economic diversity among its counties. Eastern Sichuan is characterised by plains and hills with a dense population, whereas Western Sichuan is a sparsely populated mountainous area. Like China as a whole, the eastern region of Sichuan experiences greater economic development when compared with the western region. Healthcare service utilisation varies significantly across the 183 counties that comprise Sichuan. While in-hospital delivery rates between 2016 and 2020 have consistently exceeded 99% for the whole of Sichuan, there have been wide country-level variations with rates as low as 68%. Such country-level variation serves as the basis for the development of our statistical model and enhances the generalisability of our study findings.

Outcome and exposure variables

This cross-sectional study was conducted at the county level, encompassing 183 counties in Sichuan Province annually from 2016 to 2020. The in-hospital delivery rate per county per year served as the outcome variable. It is defined as the proportion of births that occurred in medical institutions within the administrative jurisdiction of each county in a given year, representing the utilisation of obstetric services. The data were obtained from the Health Commission of Sichuan Province. The exposure variable of interest was the distance between mothers and obstetric hospitals, necessitating estimation of the distance to travel between hospitals and residents.

The estimated distribution and number of pregnant women were used to measure delivery demand.[31] Population counts data from WorldPop, organised as grid cell data, provided latitude and longitude coordinates for each population point.[32] Birth rate data from the health statistical yearbook of Sichuan Province helped estimate the number of pregnant women at each population point.[13] Birth rate refers to the ratio of the number of births to the average population during a certain year.

To determine the locations of obstetric hospitals, lists of healthcare hospitals offering obstetric delivery services were compiled from discharge records each year.[14 30] The names and addresses of these hospitals were used to obtain latitude and longitude coordinates via the Baidu API, a widely used mapping application in China.[33 34]

Driving time between each population location point and obstetric hospitals was calculated using road network data of Sichuan Province retrieved from the National Catalogue Service for Geographic Information System.[35] Average speeds for different road types were applied, as specified by the Regulation of Road Transportation Facilities for Safety (JTG D81-2017). ArcGIS V.10.5 was used to calculate the shortest travel time. Administrative boundary data used for mapping were also obtained from the National Catalogue Service for Geographic Information System, which are publicly available and serve as the base layer for our geographic analyses.[35]

Given the county-level analysis, individual-level variables like distance needed aggregation at the county level. Two indicators were chosen to measure distance at this level: the proportion of **P**regnant **W**omen covered within a **2**-hour driving radius (PW2 coverage proportion), and the maximum driving time from each population point to the nearest obstetric facility (shortest driving time) within each county.[36–38] The PW2 coverage proportion for each county was calculated by dividing the number of pregnant women who had at least one obstetric facility within a 2-hour radius by the total number of pregnant women in that county.

Directed Acyclic Graph

This study focused on the causal effect of distance on the in-hospital delivery rate. DAG was applied for finding a minimally sufficient adjustment set of confounders for this causal effect.[39] DAG is a widely used causal inference method in epidemiology to systematically represent causal relationships, providing visual diagrams of the assumed data-generating process.[40]

The DAG constructed for this study (figure 1) was based on a framework derived from a systematic review, which identified four categories of factors influencing the utilisation of in-hospital delivery services: social culture factors, perceived benefit and need, financial accessibility and spatial accessibility.[41] DAGitty, a web-based software, was used to draw the DAG.[42] Online supplemental file 1 described how we established this DAG.

In the DAG, nodes represented variables, and arrows depicted causal pathways. The minimal adjustment set included two types of factors: residential characteristics and transportation-related factors. Residential characteristics such as urban/rural area, ethnic minority area, urbanisation rate, per capita GDP and average education years were selected for adjustment, with data sourced from the statistical bureau of Sichuan Province and the 7th China Population Census databases. Transportation factors were restricted to vehicle usage, with road speed limited to average values when calculating travel time. Thus, only residential characteristics were adjusted as confounders in statistical models. Additionally, transportation might have a modifying effect on the causal relationship under investigation. For instance, better transportation infrastructure could mitigate the impact of distance on the willingness and utilisation of in-hospital delivery services. Road construction, influenced by economic development levels, may modify the causal effect, leading to heterogeneity in outcomes.

Multilevel regression models

The analysis unit comprised each county in each year, exhibiting partial independence due to data similarities within the same county across different years. The dataset had a two-level structure: the first level corresponded to time (years), and the second level represented counties, each with five time points (2016 to 2020). Given this hierarchical data structure, a two-level regression model was appropriate.[43]

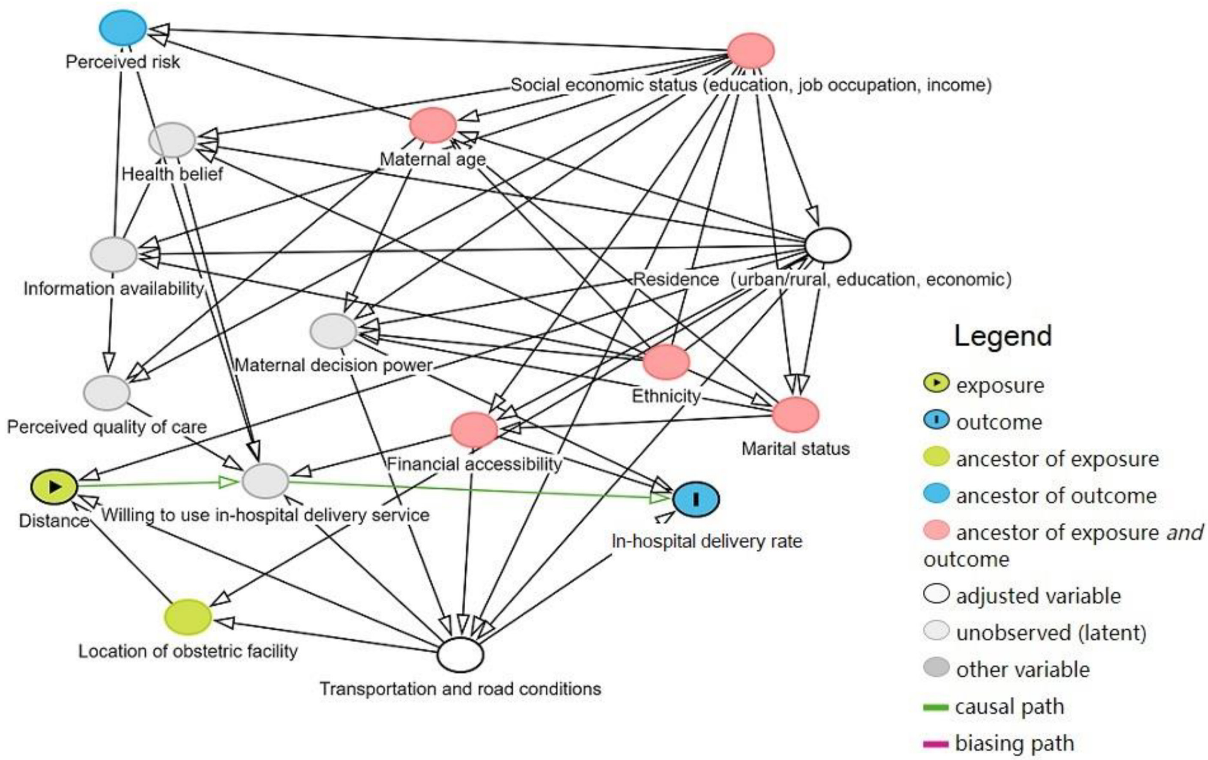

Figure 1 Directed Acyclic Graph illustrating the assumed causal relationship between distance and in-hospital delivery rate.

In these hierarchical models, the outcome variable was the in-hospital delivery rate, while the exposure variable of interest was distance, which was measured by two indicators. A two-level random intercept model (Equation 1) was used to explore the causal effect of distance on the in-hospital delivery rate. Furthermore, a two-level random slope model (Equation 2) was employed to investigate potential effect heterogeneity.

Two-level random intercept model

$$y_{tc} = \beta_{0c} + \beta_1 x_{tc} + \mathbf{L}\lambda + e_{0tc}$$
$$\beta_{0c} = \beta_0 + u_{0c} \tag{1}$$

Here, c represented the county, a t represented the year, y_{tc} denoted the in-hospital delivery rate for county c in year t, x_{tc} represented the distance indicator (shortest driving time or PW2 coverage proportion), $\mathbf{L}\lambda$ represented the confounders and their coefficients, β_1 was the parameter of interest measuring the average effect of distance on the in-hospital delivery rate, u_{0c} represented the level 2 residual (county level), and e_{0tc} represented the residual at the level 1 (observational level).

Two-level random slope model

$$y_{tc} = \beta_{0c} + \beta_{1c} x_{tc} + \mathbf{L}\lambda + e_{0tc}$$
$$\beta_{0c} = \beta_0 + u_{0c} \tag{2}$$
$$\beta_{1c} = \beta_1 + u_{1c}$$

In the random slope model, the coefficient of distance β_{1c} was no longer a constant, allowing for heterogeneity in the effect of distance across different counties. The random error term u_{1c} captured the county-specific deviations from the average effect of distance, acknowledging that the relationship between distance and the in-hospital delivery rate might vary between counties. Interaction terms could also be included to explore further heterogeneity in the causal effect.

Sensitivity analysis

Fixed effect model and quantile regression model were used for sensitivity analysis to address potential limitations in the previous analysis, particularly concerning the reliance on the DAG and the possibility of omitted variables leading to confounding effects. The fixed effect model was employed to control for fixed confounding effects from county and time by generating county and time dummy variables separately.

Fixed effect model

$$y_{tc} = \beta_1 x_{tc} + \alpha_c + \mathbf{L}\lambda + \varepsilon_{tc} \tag{3}$$

$$y_{tc} = \beta_1 x_{tc} + \gamma_t + \mathbf{L}\lambda + \varepsilon_{tc} \tag{4}$$

Similar to previous equations, dependent variable y_{tc} denoted the in-hospital delivery rate for county c in year t, x_{tc} represented the distance indicator, $\mathbf{L}\lambda$ represented the confounders and their coefficients, ε_{tc} represented the random effect, α_c represented the dummy variables for county, and γ_t represented the dummy variables for year. The coefficient β_1 measured the average causal effect of the exposure variable.

Additionally, a quantile regression model was used to explore heterogeneity in the causal effect, capturing

Table 1 Descriptive characteristics of study counties

Variables	No. (%)	Min	Median	Max
Number of county No. (%)	915* (100.00)			
Types of county No. (%)				
Urban area	354 (38.69)			
Rural area	561 (61.31)			
Ethnic minority area				
Yes	250 (26.29)			
No	665 (73.71)			
Proportion of pregnant women covered within a 2-hour driving radius (%)		2.26	99.21	100.00
The maximum value of the shortest driving time (min)		25.87	119.87	293.65
In-hospital delivery rate (%)		68.10	99.97	100.00
Urbanisation rate (%)		5.12	42.01	100.00
Per capita GDP (thousand yuan)		8.34	37.38	161.66
Education years on average (year)		4.85	8.45	12.51

*915 refers to the number of specific county-year observations.
GDP, gross domestic product.

variations in the distance effect across different quantiles of the outcome variable.

Quantile regression model

$$\hat{\beta}_t = argmin \sum_{i=1}^{n} \rho_t \left(y_i - \beta_\tau x_i \right)$$
$$\rho_t \left(u \right) = \left(\tau - I \left(u < 0 \right) \right) u \quad (5)$$

In this model, y_i indicated the ith independent variable, x_i was the correspondent independent variable and τ represented the quantile number, with 0.5 indicating the median. The check function $\rho_t(\cdot)$ defined weights by a piecewise function $I(\cdot)$, where $I(\cdot)$ is the indicator function that equals 1 if the condition is true and 0 otherwise. The quantile regression was conducted by the package called 'quantreg' in R, employing the 10-quantile method w to calculate the regression coefficients for the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th and 95th quantiles. Model fitting was completed using the default br algorithm (Barrodale and Roberts), and standard errors were calculated using bootstrap methods.

RESULTS

Descriptive analysis results

Table 1 presents the preliminary county-level descriptive characteristics over the study period 2016–2020. Sichuan Province has a total of 183 counties, and over the 5-year study period, this amounted to 915 county-year observations. Most counties were classified as rural areas, accounting for 61.31% of the sample. More than 26% of counties were ethnic minority areas. Regarding the PW2 coverage proportion indicator, values for over half of the counties were above 99%. However, the lowest PW2 coverage proportion was 2.26%, which indicates that in this county, only a small fraction of pregnant women are able to reach the closest obstetric hospitals within a 2-hour drive. For another indicator, more than 50% of counties had maximum values for the shortest driving time below 120 min. To provide a visual representation, these two indicators were depicted in online supplemental figures 1 and 2, respectively. The number of obstetric hospitals in Sichuan Province fell from 1209 in 2017 to 951 in 2020. The adverse consequence of this reduction in the number of hospitals was evidenced by the slightly increased shortest driving time and the decreased PW2 coverage proportion (table 2). The maximum shortest driving time fluctuated slightly over the years but increased overall from 117.244 min in 2017 to 121.035 min in 2020. Similarly, the proportion of pregnant women covered within a 2-hour driving radius initially increased from 97.162% in 2016 to 97.723% in 2018, but then declined to 97.100% in 2020. The lowest in-hospital delivery rate was 68.10%, while most counties reported values above 95%. The variation among

Table 2 Time trend of two distance indicators

Year	Proportion of pregnant women covered within 2-hour driving radius (%)	The maximum value of the shortest drive time (minutes)
2016	97.162	119.307
2017	97.414	117.244
2018	97.723	117.244
2019	97.394	119.976
2020	97.100	121.035

counties provided the basis for data analysis (online supplemental figure 3).

To address the issue of collinearity among independent variables, a correlation analysis and the Spearman rank correlation coefficients were presented in online supplemental table 1. This analysis revealed a strong correlation between the two indicators of distance and the ethnic minority variable. Additionally, strong correlations were observed among the variables of urbanisation rate, per capita GDP and average education years, with correlation coefficients around 0.7. The rural variable also showed a strong correlation with the urbanisation rate. Taking these factors into consideration, we decided to keep two confounders: the rural variable and per capita GDP.

Regression analysis results

The results of the multilevel regression models, as summarised in table 3, shed light on the associations between distance and in-hospital delivery rate. Model

Table 3 Results of multilevel regression models

Estimator (95% CI)	Model 1	Model 2	Model 3	Model 4	Model 5
Fixed estimator					
β_0 intercept	98.665*** (98.416 to 98.914)	98.665*** (98.228 to 99.102)	85.622*** (84.134 to 87.113)	101.099*** (100.143 to 102.051)	85.451*** (83.3478 to 87.563)
β_1 PW2 coverage proportion			14.254*** (12.6501 to 15.852)		14.356*** (12.519 to 16.185)
β_2 shortest driving time				−0.020*** (−0.026 to −0.013)	0.001 (−0.004 to 0.006)
Random estimator					
σ^2_{u0} variance of intercept Level 2		7.572*** (5.949 to 9.700)	2.090*** (1.447 to 2.921)	6.205*** (4.825 to 8.013)	2.087*** (1.444 to 2.918)
σ^2_{e0} variance of residual at Level 1	14.669*** (13.412 to 16.113)	7.082*** (6.403 to 7.860)	6.921*** (6.257 to 7.681)	7.101*** (6.420 to 7.881)	6.921*** (6.258 to 7.682)
−2 log likelihood	5053.151	4725.941	4535.128	4697.777	4535.078

Estimator (95% CI)	Model 6	Model 7	Model 8	Model 9	Model 10
Fixed estimator					
β_0 intercept	86.291*** (84.591 to 87.992)	85.548*** (84.083 to 87.0130)	85.105*** (83.351 to 86.848)	71.123*** (68.479 to 73.713)	83.441*** (78.283 to 88.675)
β_1 PW2 coverage proportion	13.831*** (12.152 to 15.506)	13.052*** (11.406 to 14.685)	13.217*** (11.533 to 14.891)	28.127*** (25.370 to 30.942)	16.066 *** (10.747 to 21.323)
β_2 rural	−0.459 (−1.033 to 0.115)		0.299 (−0.340 to 0.945)		
β_3 per capita GDP		0.026*** (0.016 to 0.037)	0.029*** (0.0178 to 0.040)	0.585*** (0.498 to 0.673)	0.010** (0.0034 to 0.017)
β_4 PW2 coverage proportion * per capita GDP				−0.576*** (−0.667 to −0.488)	
Random estimator					
σ^2_{u0} variance of intercepts at level 2	2.043*** (1.408 to 2.864)	2.012*** (1.384 to 2.827)	2.023*** (1.393 to 2.841)	1.862*** (1.292 to 2.605)	312.343 *** (141.10 to 847.06)
$\sigma^2_{U_1}$ variance of slopes at level 2					314.6843 *** (140.96 to 857.55)
$\sigma_{U_0U_1}$ Covariance at level 2					−313.511 *** (−852.29 to −141.17)
σ^2_{e0} variance of residual at level 1	6.921*** (6.258 to 7.681)	6.730*** (6.083 to 7.471)	6.718*** (6.072 to 7.458)	5.584*** (5.044 to 6.203)	5.663 *** (3.07 to 6.16)
−2 log likelihood	4532.665	4508.441	4507.602	4349.904	4448.016

PW2 coverage proportion represents the proportion of pregnant women covered within a 2-hour driving radius; shortest driving time refers to the maximum shortest driving time within county.
Significant: '***' p<0.001, '**' p<0.01, '*' p<0.05. 95% CI: profile likelihood method was used except for Model 10, where parametric bootstrap (R=1000) was applied due to singular fit. Model 7 was selected as the final model after adjusting for confounders. Model 9 included an interaction between per capita GDP and PW2 coverage proportion. Model 10 examined county-level heterogeneity (random slope model).
GDP, gross domestic product.

1, an ordinary linear regression model, was compared with Model 2, a two-level model incorporating county and time levels. The higher SE of the intercept in Model 2 and its statistically significant residual variance at the county level indicated the appropriateness of the two-level model, with an intraclass correlation coefficient of 0.517, signifying substantial data clustering at the county level.

Models 3 to 5 explored the effects of two distance indicators. The coefficients for distance indicator were 14.254 in Model 3 and −0.020 in Model 4, respectively, indicating that a higher PW2 coverage proportion and shorter driving time were associated with a higher in-hospital delivery rate. Model 5 included both indicators simultaneously and revealed that the coefficient for the PW2 coverage proportion remained statistically significant (β=14.356, 95% CI: 12.519 to 16.185, p<0.001), whereas the coefficient for shortest driving time was not statistically significant (β=0.001, 95% CI: −0.004 to 0.006). Consequently, only the PW2 coverage proportion indicator was retained.

The rural variable and per capita GDP were added separately to Models 6 and 7. Model 8 included both potential confounders. The results showed that the estimator for the rural variable was not statistically significant. The likelihood test indicated no significant difference between Models 7 and 8. Therefore, Model 7 was selected as the final model for subsequent interpretation, as it retained per capita GDP as the only confounder.

To explore the effect of heterogeneity, Model 9 introduced an interaction term between the PW2 coverage proportion and per capita GDP. The negative coefficient (−0.576) suggested a smaller causal effect of PW2 coverage proportion on the in-hospital delivery rate in developed areas compared with less developed areas. Additionally, Model 10, using a random slope model, illustrated the variation in causal effects among counties. Online supplemental figure 4a depicted the correlation between the fitted values and PW2 coverage proportion for each county, while online supplemental figure 4b showed the relationship between variance among counties and PW2 coverage proportion.

The multilevel regression models underscored the causal effect of PW2 coverage proportion on in-hospital delivery rates. Based on the final selected model (Model 7), a 1 percentage point increase in PW2 coverage proportion led to a 13 percentage point (95% CI: 11.406 to 14.685) increase in in-hospital delivery rates, after controlling for per capita GDP. Notably, the impact of PW2 coverage proportion was pronounced in areas with low per capita GDP, with significant differences in in-hospital delivery rates observed among counties with low PW2 coverage proportions.

Sensitivity analysis results

Fixed effect models (online supplemental table 2), incorporating county and year dummy variables, yielded coefficient estimates for the PW2 coverage proportion variable (12.740 and 13.562) consistent with those from the multilevel regression model (13.052), indicating statistical significance and reinforcing the stability of our results.

Quantile regression analysis (online supplemental figure 5 and online supplemental table 3) revealed varying impacts of distance on in-hospital delivery rates across districts and counties, with greater effects observed in areas with lower delivery rates (smaller quantiles). These findings align with those of the two-level random slope model, further validating our conclusions.

DISCUSSION

Main findings

Following the reduction in obstetric hospitals from 1209 in 2017 to 951 in 2020, the PW2 coverage proportion decreased from 97.4% to 97.1% at the county level in 2020, while the maximum shortest driving time increased from 117.2 min in 2017 to 121.0 min. Regression model results as the distance between a pregnant woman's residence and obstetric hospitals increased, the utilisation rate of in-hospital delivery decreased. Based on the final selected model (Model 7), a 1 percentage point increase in PW2 coverage proportion was associated with a 13 percentage point increase (95% CI: 11.4 to 14.7) in in-hospital delivery rates, after controlling for per capita GDP. This causal effect exhibited heterogeneity, with distance exerting a greater impact on the utilisation of in-hospital delivery services in counties with lower economic levels, lower PW2 coverage proportions and lower in-hospital delivery rates.

Literature contribution

Internationally, most low- and middle-income countries (LMICs) are focused on expanding hospitals, while high-income countries (HICs) prioritise reducing them.[10 44] To the best of our knowledge, this is the first study to provide evidence of the reduction in obstetric hospitals and its impact on distance in LMICs.

Our regression model results align with previous studies, reinforcing the well-documented impact of distance on in-hospital delivery rates.[5 45–47] Previous evidence in China regarding the influence of distance on in-hospital delivery rates is outdated. The lack of recent research in the past decade may be partly attributed to the high in-hospital delivery rates, which have exceeded 99% since 2013.[22] Additionally, significant improvements in rural road infrastructure, driven by economic development and poverty alleviation initiatives, have further reduced geographical barriers to accessing healthcare services. Consequently, geographic barriers have received less attention. However, this study readdresses the distance issue by examining the causal effect of distance on in-hospital delivery rates. Increased distance might be a common challenge for reducing maternal mortality in similar middle-income countries, which are experiencing imbalanced and rapid development across different counties, alongside declining birth rates and anticipated reductions in obstetric hospitals.

While some research suggests that spatial accessibility may not be the primary consideration for patients seeking medical treatment, as evidenced by the phenomenon of 'bypassing', whereby patients opt for higher-quality institutions farther away, this does not negate the impact of distance on patients' willingness to seek care.[19 48] The result of the DAG model highlights the confounding influence of county characteristics on the role of distance. This phenomenon may be attributed to the clustering of similar populations,[41] where community norms and social influences play a pivotal role in shaping healthcare utilisation patterns.[49 50] If societal norms default to in-hospital delivery service, even individuals with unfavourable characteristics may opt for it.[51] The DAG result also reveals that factors influencing in-hospital delivery rate may differ from those affecting the impact of distance. The DAG visualises the assumed complex relationships among variables. Combined with multilevel regression models and sensitivity analysis, the results provide a robust evidence of the causal effect of distance.

Policy implication

The study findings underscore the enduring influence of distance on in-hospital delivery rates, particularly in counties facing reductions in obstetric hospitals. Vulnerable counties with lower economic status, limited PW2 coverage proportions and lower in-hospital delivery rates are disproportionately affected. To address these disparities and ensure equitable access to obstetric care, policymakers must prioritise spatial accessibility considerations in resource allocation strategies.

Various optimisation functions are available when optimising the locations for obstetric hospitals. Taking one of the common methods as examples, in the location-allocation model method, three models are typically employed to determine a fixed number of sites for facility locations.[52] The P-median problem model (P-median model) focuses on minimising the population-weighted sum of travel time meanwhile may neglect accessibility equity. The P-centre problem model (P-centre model) aims to minimise the travel time. The maximal covering location problem (MCLP) model seeks to maximise the PW2 coverage proportion. The existence of the causal effect of distance suggests that the P-median model may not be a suitable option as it can lead to suboptimal resource allocation in areas with sparse populations. Comparison results between two distance indicators suggest that expanding PW2 coverage proportion is more crucial than shortening the travel time. Therefore, the MCLP model is more suitable for location optimisation than the P-centre model.

Due to the high cost associated with allocating obstetric hospitals in rural areas, policymakers often consider alternative approaches to address this challenge. For instance, the establishment of maternity waiting homes (MWHs) and birthing centres and the promotion of safe home births are commonly explored options. MWHs are independent or affiliated houses around obstetric hospitals where pregnant women can stay before giving birth. Many LMICs, such as Ethiopia, Cuba, Malawi, Eritrea and Zimbabwe, have built MWHs.[53 54] Meanwhile, research from HICs suggests that the COVID-19 pandemic accelerated the shift toward out-of-hospital births due to concerns about infection risk, healthcare system disruptions and restrictions on family presence during hospital stays.[55 56] In contrast, China has maintained a predominantly hospital-based delivery system, with Sichuan Province's in-hospital delivery rate remaining stable at 99.83% in both 2019 and 2020, suggesting minimal impact of the pandemic on institutional deliveries. This reflects broader challenges in promoting safe home births in China, where hospital deliveries continue to be prioritised as a key strategy for reducing adverse maternal and neonatal health outcomes.

Safe deliveries in settings such as birthing centres and home births require three important conditions: risk assessment and triage for pregnant women, trained midwives, and efficient and timely referral transport systems to ensure that patients can be transferred to higher-level hospitals for treatment in emergencies.[57] With regard to risk assessment, China's current 'Standards for the Risk Assessment and Management of Pregnant Women' assigns pregnant women to one of five risk levels and triages them, accordingly, thereby meeting the first condition. Regarding midwives, the current supply of midwives has been shown to be insufficient in China.[58] Compared with international standards, midwifery training in China has disadvantages such as low admission qualifications, irregular training, insufficient training in managing high-risk pregnancies and limited development of continuing education.[58] With regard to the transport system, the construction of transportation networks is still in its early stages. The National Health Commission issued the 'Guidelines for the Construction and Management of Centers for Treating Critically Ill Pregnant Women' in 2018, which lacks detailed requirements for the configuration of treatment networks and methods for evaluating their operational effectiveness. The current emergency medical service network is difficult to effectively cover rural areas in a timely manner.[59] In summary, out-of-hospital deliveries pose high risks and are not suitable for China's current situation. However, they could become a viable solution with the presence of more high-quality midwives and efficient referral transportation systems. Meanwhile, centralisation obstetric resources may improve service quality.[14] Therefore, the optimisation of obstetric resource allocation needs to balance the influence of spatial accessibility and the potential benefits of resource centralisation.

Limitation

This study presents several limitations. First, the use of driving time as a measure of distance overlooks real-time road conditions, such as traffic congestion or weather, potentially underestimating travel time. Second, the study only considers travel by private car, neglecting other modes of transportation like motorcycles or public buses, which may affect families and regions with lower economic status differently. Third, the constructed DAG makes assumptions regarding the independence of obstetric hospital distribution from individual characteristics after adjusting for residential characteristics. Moreover, the study primarily examined planned childbirth and did not address emergency situations requiring immediate and effective treatment, which could potentially limit the generalisability of the results. Finally, the DAG setup relies on the current understanding derived from literature, which may introduce bias by overlooking omitted variables or causal relationships, thereby affecting the accuracy of estimated values. While DAG visualisation aids in understanding data generation mechanisms, ongoing modifications based on emerging evidence are necessary to reduce bias and improve model accuracy.

CONCLUSION

This study illustrated the impact on distance of the decreasing number of obstetric hospitals in China, a rapidly developing LMIC with an imbalanced development and declining birth rate. Using causal inference methods and multilevel regression models, it validated the effect of distance on the in-hospital delivery rate, further emphasising the importance of distance in accounting for variations in the use of medical resources. These findings assist decision-makers in promptly identifying priority intervention targets and determining optimisation goals for the location of obstetric hospitals. Meanwhile, centralising obstetric resources in better-equipped facilities may help improve service quality, as commonly seen in high-income countries. Therefore, the optimisation of obstetric resources needs to balance the impact of spatial accessibility with the potential benefits of resource centralisation.

Author affiliations
[1]HEOA Group, West China School of Public Health and West China Fourth Hospital, Sichuan University, Chengdu, Sichuan, China
[2]Institute for Healthy Cities and West China Research Center for Rural Health Development, Sichuan University, Chengdu, Sichuan, China
[3]Department of Obstetrics and Gynaecology, Faculty of Medicine, The University of British Columbia, Vancouver, British Columbia, Canada
[4]Women's Health Research Institute and Partnership for Women's Health Research Canada, BC Women's Hospital, Provincial Health Services Authority, Vancouver, British Columbia, Canada
[5]Institute of Health Policy, Management and Evaluation, University of Toronto, Toronto, Ontario, Canada

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ORCID iDs
Nan Chen http://orcid.org/0000-0001-8684-7971
Jay Pan http://orcid.org/0000-0001-9501-1535

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