

RESEARCH ARTICLE

Analysis of birth rate in mainland China under the continuous adjustment of the family planning policy

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Abstract

The birth rate in mainland China declined from 12.95‰ in 2016 to 6.39‰ in 2023, posing significant challenges to social harmony and sustainable development. To evaluate the effectiveness and impact of family planning policy adjustments, this study collected birth rate and population data for mainland China (2007 – 2023) and eight provinces, including Shanghai and Beijing (provincial-level municipalities), Xinjiang, Heilongjiang, Hunan, Hebei, Hainan, and Guangdong. Using Joinpoint regression and autoregressive integrated moving average models, we analyzed birth rate trends, assessed the stimulatory effects of four family planning policy adjustments (2011 – 2021), and projected future birth rate trajectories for both mainland China and the selected provinces. The findings show that the partial two-child policies (2011, 2013) stabilized national birth rates and triggered short-term regional increases. The universal two-child policy (2016) caused a temporary surge, followed by a continued linear decline. The three-child policy (2021) failed to reverse this trend and had a negligible impact. Key drivers include a 19% decrease in the population of women of childbearing age and a 34% decline in childbearing willingness. Projections from birth rate models (2024 – 2030) demonstrate a continued national decline, with significant regional disparities in both demographic characteristics and policy responsiveness. To address these dual challenges, China must implement comprehensive reforms to its national family planning policies to support sustainable social development, alongside province-specific interventions tailored to local demographic conditions to maintain regional balance.

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1. Introduction

The birth rate is a vital demographic indicator that reflects a nation's potential for sustainable development (Nandi *et al.*, 2019; Yakita, 2018). In mainland China, socioeconomic evolution and shifting family values have contributed to a persistent decline in birth rates (Zhang *et al.*, 2022). To address demographic imbalances, the

Chinese government has progressively relaxed its family planning policies since 2011 (Du & Dong, 2024). Initially enforcing a strict one-child policy, the reforms were introduced in phases: permitting dual-only-child couples in which both partners were only children to have a second child (2011), extending eligibility to couples where one partner was an only child (2013), universalizing the two-child policy (2015), and finally implementing the three-child policy (2021).

Despite the relaxation of family planning restrictions through these policy adjustments, which theoretically should have led to a sustained increase in birth rates, China's birth rate has not shown stable growth. On the contrary, it declined from 12.95‰ in 2016 to 6.39‰ in 2023. This counterintuitive trend indicates that the family planning policy reforms have failed to achieve their intended stimulatory effect on fertility, which also suggests that China's low fertility challenge may be more severe than the raw data implies (Chen *et al.*, 2025). Consequently, a comprehensive analysis of China's fertility issues is crucial for the nation's sustainable development.

Recent demographic studies have uncovered novel insights into global fertility trends that may shed light on China's declining birth rates. Interrupted time-series analyses across 28 European countries revealed a 14 – 22% decline in birth rates attributable to the COVID-19 pandemic (Pomar *et al.*, 2022), while spatial regression studies in Mexico demonstrated strong negative correlations between pandemic severity and fertility indicators (Azcorra *et al.*, 2023). These findings are further supported by subsequent research examining pandemic-related demographic shifts (Babu & Padma, 2024; Shiva & Mohsen, 2024).

In China's unique demographic context, researchers have developed innovative analytical approaches to address the complexities of fertility pattern analysis. Advanced time-series modeling has revealed significant autocorrelation structures within birth rate datasets (Wang & Wu, 2023), while machine learning frameworks integrating multidimensional socioeconomic variables have demonstrated enhanced predictive capabilities (Zhang, 2024). Methodological advancements have also included the application of non-linear growth modeling (Zhu & Qiao, 2018) and fuzzy time-series analysis (Ye & Zheng, 2023), yielding deeper insights into the multifactorial determinants influencing fertility behaviors.

Despite significant methodological progress, the current modeling approaches remain constrained by China's dynamic policy landscape (Liang & Li, 2024; Song *et al.*, 2025; Song & Wen, 2015; Xu *et al.*, 2022; Zhong, 2016). Empirical evidence from Liu *et al.*'s (2016) logistic regression analysis (odds ratio [OR] = 0.67 for second

births) and Zhu's (2014) longitudinal cohort studies (which documented a decline in fertility intentions from 1.8 to 1.2 children) consistently demonstrates that even extensive policy liberalizations have yielded only limited improvements in fertility preferences. These persistent limitations highlight the critical need for advanced analytical frameworks that integrate behavioral economic determinants, multigenerational transmission mechanisms, and subnational heterogeneity in policy implementation. Such enhanced models would substantially improve predictive accuracy during China's unprecedented demographic transition.

In response, this study employs Joinpoint regression and autoregressive integrated moving average (ARIMA) models to analyze birth rate data from 2007 to 2023 within the context of China's family planning policy adjustments, offering new insights into the country's fertility transition and informing potential policy optimization strategies.

2. Data and methods

2.1. Data

This study utilized birth rate data (2007 – 2023) from China's National Bureau of Statistics and provincial statistical bulletins. To ensure regional representativeness, eight provinces were selected from mainland China's 31 administrative divisions, stratified by annual average birth rate:

- High birth rate provinces (20% above the mainland average): Xinjiang, Hainan
- Low birth rate provinces (20% below the mainland average): Heilongjiang, Beijing, and Shanghai
- Medium birth rate provinces (within $\pm 20\%$ of the mainland average): Guangdong, Hebei, and Hunan.

Notably, Beijing, Shanghai, and Guangdong rank among China's most economically advanced areas, while the others exhibit moderate development. The birth rate data for mainland China and eight selected provinces from 2007 to 2023 are detailed in Table A1.

Beyond fertility willingness, birth rates are influenced by the size of the childbearing-age population. To assess this, age-stratified population data (2007 – 2023) were extracted from the Global Burden of Disease Study (GBD 2021) (<https://ghdx.healthdata.org/>). These metrics, detailed in Table A2, enable analysis of the demographic shifts underlying fertility trends.

2.2. Methods

Given the substantial influence of family planning policies on fertility patterns, birth rate trends may exhibit significant variations across different policy phases. The Joinpoint

model (Clegg *et al.*, 2009; Kim *et al.*, 2000; Rose *et al.*, 2015) offers particular advantages, as it automatically partitions the birth rate trajectory into discrete temporal segments, enabling detailed characterization of trends within each interval. The model's algorithm identifies joinpoints where significant trend alterations occur, selecting the optimal joinpoints through minimization of the mean squared error. This approach significantly strengthens the scientific validity and precision of trend analysis (Islami *et al.*, 2021; Moreno-Agostino *et al.*, 2021; Weir *et al.*, 2015). The birth rate data were analyzed using Joinpoint Regression Software (version 5.3.0.0), which incorporates evaluation criteria such as the Bayesian Information Criterion (BIC) for phase division and turning point calculation, enabling autonomous optimization computation. Consequently, the software was employed to determine the optimal phase divisions for birth rate trends and the locations of joinpoints, without presetting the number of change points. Subsequently, accounting for family planning policy adjustments, the number of joinpoints was manually specified as four (three for Heilongjiang province due to the lack of data before 2011), with the software calculating their optimal positions to evaluate the stimulatory effects of different policy interventions. Finally, a comparative analysis of both computational approaches was conducted to assess the relative strength of policy-induced effects.

For predictive modeling, an ARIMA model (Giglio *et al.*, 2022) was developed using RStudio (version 2024.04.2) with an R 4.4.1 environment. The ARIMA framework provides robust analytical capabilities for time series data, generating forecasts by leveraging historical patterns (Helfenstein, 1991; Zhang, 2003). The model incorporates three fundamental parameters: (p) autoregressive terms accounting for time-lagged effects, (q) moving average components addressing residual noise, and (d) differencing operations ensuring time series stationarity (Wang *et al.*, 2022). Widely utilized in economic and medical research, ARIMA modeling offers reliable predictive performance when stationarity requirements are satisfied (Pai & Lin, 2005; Wang *et al.*, 2005). In this study, the "auto.arima" function from R version 4.4.1 was employed to construct ARIMA models. This function automatically configures parameter search strategies and computes parameter values, recommending the optimal model based on multiple criteria, including Akaike Information Criterion (AIC)/Bayesian Information Criterion (BIC) and the Ljung-Box test. Data from all provinces were processed uniformly to determine the best-fitting model, after which each model underwent separate significance testing.

The synergistic application of Joinpoint regression for trend decomposition and ARIMA modeling for predictive analytics yields a methodologically robust framework

for examining birth rate dynamics amidst evolving population policies. This dual approach enhances both the interpretability of historical trends and the reliability of future projections.

3. Results

3.1. Temporal segmentation of China's birth rate patterns using Joinpoint regression

The Joinpoint model was applied to analyze the birth rate data without predefining the number of joint points. The analytical results are presented in Figure 1. When family planning policy adjustments are not considered, the birth rate data for mainland China can be categorized into two distinct phases. The initial phase, covering 2007 to 2017, demonstrated a gradual upward trend with an annual percentage change (APC) of 0.43. Conversely, the subsequent phase, from 2017 to 2023, revealed a sharp downward trajectory, registering an APC of -11.10.

The birth rate trends in Shanghai and Beijing showed complete consistency with the national pattern observed in mainland China. Similarly, Heilongjiang and Hebei provinces largely followed the national trend, though with a slight temporal delay. In contrast, Xinjiang, Hunan, Guangdong, and Hainan exhibited notably different birth rate patterns. The divergent trends across provinces reflect varying sensitivities to policy adjustments, while confounding factors – such as economic conditions, population migration, and fertility attitudes – may amplify, diminish, or delay policy impacts.

Two principal characteristics emerged from the analysis of birth rate trends in mainland China and the eight examined provinces: (i) from 2007 to 2017, birth rates maintained relative stability with only incremental variations; and (ii) from 2017 to 2023, birth rates entered a period of accelerated decline.

Given the substantial adjustments to China's family planning policy in 2011, 2013, 2015, and 2021, four joinpoints were specified to precisely examine the policy-birth rate relationship. Due to the unavailability of birth rate data from 2007 to 2011, only three joinpoints were set for Heilongjiang. Figure 2 presents the phase division results calculated by the Joinpoint software under the given optimal number of joint points, indicating that: (i) 2007 – 2011: a gradual birth rate decline preceded the initial 2011 policy adjustment; (ii) 2011 – 2014: modest fertility recovery, potentially falling short of expectations, prompted the 2013 policy revision; (iii) 2014 – 2017: the combined effects of 2013 and 2015 policy changes drove a transient but sharp fertility increase; (iv) 2017 – 2021: limited policy impact during this period correlated with an accelerated birth rate decline; (v) 2021 – 2023: the 2021

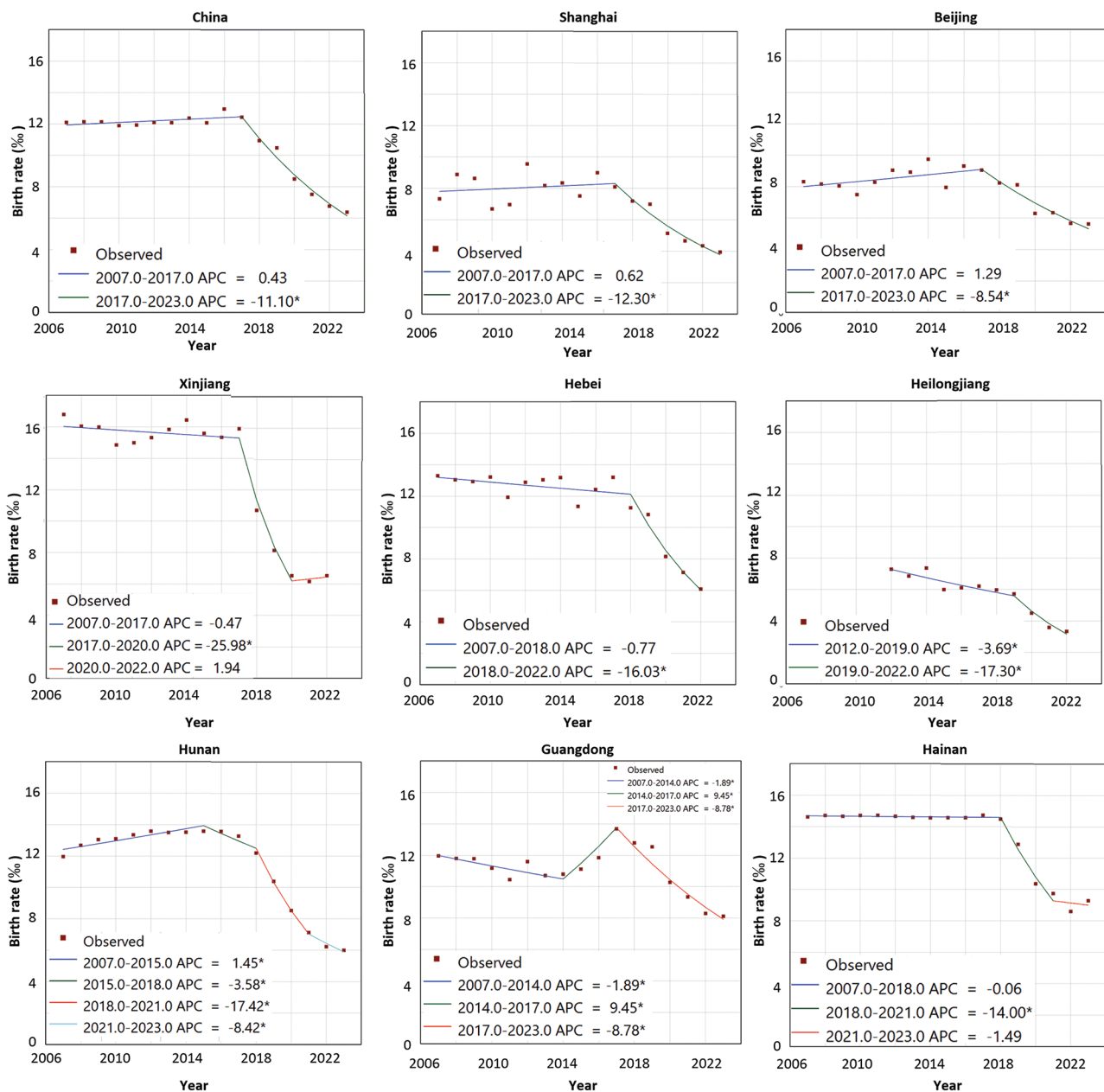


Figure 1. Joinpoint regression analysis of birth rate trends in mainland China and eight provinces
Abbreviation: APC: Annual percentage change.

policy intervention temporarily slowed, but failed to reverse the persistent downward trend. These findings underscore the nuanced dynamics between policy and fertility, where regulatory changes demonstrate time-limited effectiveness within broader demographic transitions.

Comparative analysis of Figures 1 and 2 demonstrates that every family planning policy adjustment in mainland China has induced a transient increase in birth rates.

However, these policy-driven fertility fluctuations represent not a transformation of social childbearing preferences, but rather a temporal clustering of reproductive behavior among policy-affected cohorts. The 2015 universal two-child policy exemplifies this pattern, triggering concentrated second births among eligible families during 2016 – 2017, which temporarily elevated birth rates. Both Figures 1 and 2 detected the stimulatory effect of the 2015

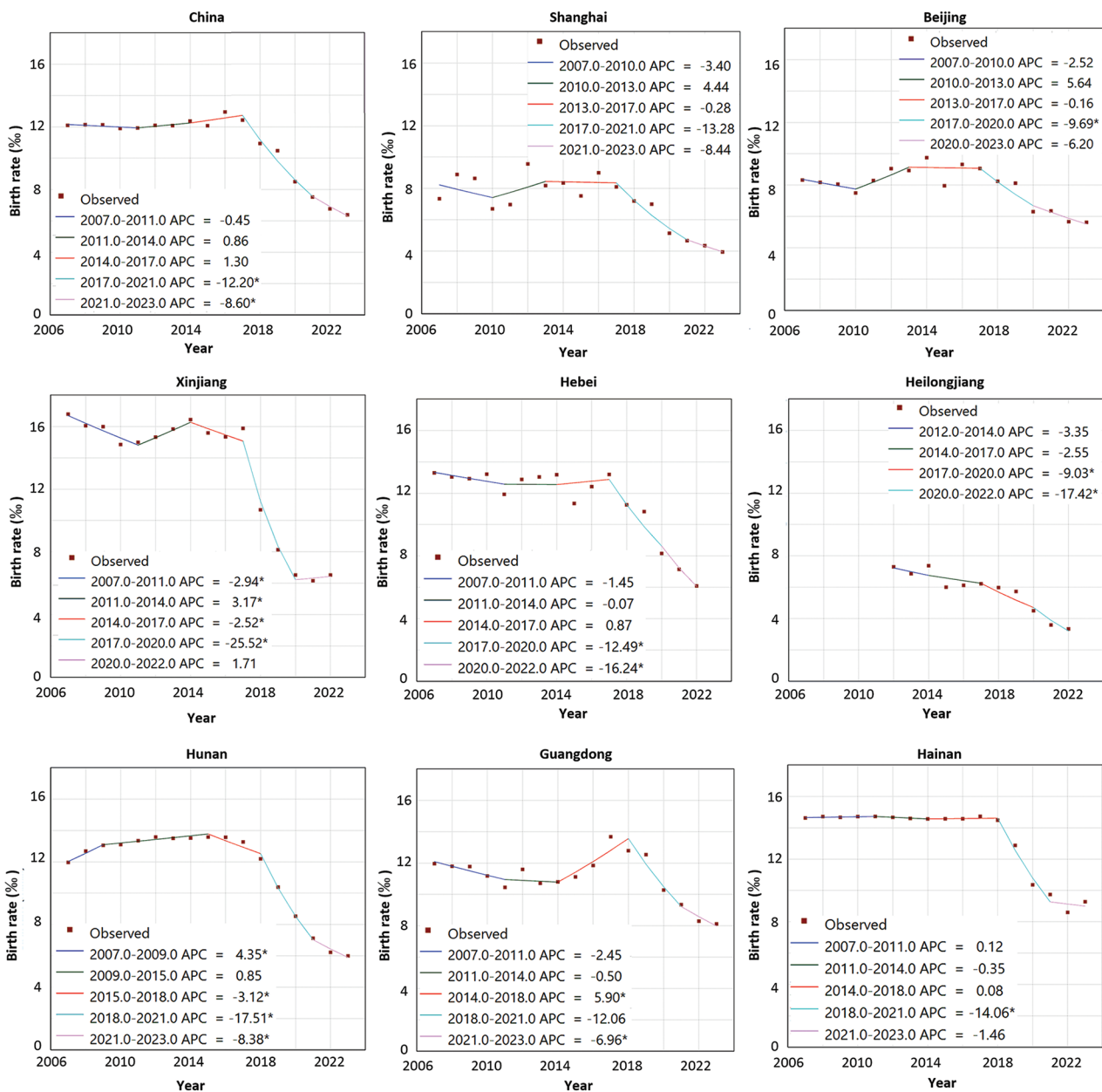


Figure 2. Policy-responsive fertility transitions: A spatiotemporal analysis of birth rates in China and eight provinces
Abbreviation: APC: Annual percentage change.

policy change, indicating that the universal two-child policy implemented had the most significant impact.

3.2. Analysis of key determinants of birth rate fluctuations

Under conditions of relative population stability, birth rate variations are primarily governed by two demographic factors: (i) the absolute size of the reproductive-age cohort and (ii) population fertility intentions. Utilizing GBD

2021 data, we quantified the reproductive-age population (2007 – 2021), with detailed stratification presented in Table A2. Given China's gender imbalance (a predominance of males over females), our analysis specifically focuses on the female reproductive cohort.

In accordance with China's Marriage Law, which stipulates a minimum female marriage age of 20 years, we operationally defined the reproductive-age population as women aged 20 – 49 years. Projections for 2022 – 2023

were derived by extrapolating from baseline populations of females aged 10 – 20 and 40 – 49 years in 2021.

Figure 3 illustrates the temporal trajectory of China's female reproductive-age population (2007 – 2023). Data for 2022 – 2023 were sourced from China's National Economic and Social Development Statistical Bulletin, while preceding years utilized GBD 2021 datasets. This demographic analysis reveals critical structural shifts in the population that fundamentally constrain birth rate dynamics.

Mainland China's total population maintained consistent growth through 2021 before entering a period of modest decline during 2022 – 2023. This demographic shift contrasts sharply with trends among women of childbearing age (20 – 49 years), whose numbers grew steadily before 2012 but subsequently underwent a marked 19% contraction. The substantial reduction in reproductive-age women, occurring alongside relative stability in the overall population size, creates fundamental demographic pressures that inevitably drive declines in the birth rate.

Based on comprehensive demographic data, including mainland China's total population, annual birth figures, and female population of reproductive age (20 – 49 years), the mean number of children per woman was computed using the following formula:

$$\mu = \frac{n_p \times r \times T}{n_w} \tag{I}$$

In Equation I, μ represents the average number of children born to a single woman, n_w is the population of women of childbearing age, n_p is the total population, r is the birth rate, and T represents the duration of female reproductive age ($T=30$). The result of μ is shown in Figure 4.

The average number of children per woman serves as a crucial indicator of fertility willingness. While the birth rate peaked in 2016 and 2017, this temporary increase was directly linked to China's family planning policy adjustments, particularly the 2015 universal two-child policy. This short-term rise does not reflect a fundamental change in childbearing preferences but rather represents a concentrated realization of second-child demand among policy-affected families.

From 2007 to 2023, Chinese women's childbearing willingness has shown a clear and consistent downward trajectory. In 2007, the average stood at 1.5 children per woman, but by 2023, it had declined to 0.97 – significantly below the replacement level of 2.1 needed for population stability. This sustained decrease highlights a substantial transformation in reproductive behaviors and attitudes, influenced by multiple socioeconomic, cultural, and policy factors.

The consequences of this trend are far-reaching. Continuing fertility decline may intensify demographic challenges, including population aging and workforce contraction, creating significant obstacles for economic development and social welfare systems. Policy responses should therefore incorporate comprehensive measures to alleviate child-rearing costs, enhance work–family balance, and foster family-friendly social environments. Without such interventions, the birth rate downturn is likely to continue, with profound implications for China's future demographic and economic landscape.

3.3. Autoregressive integrated moving average model-based birth rate analysis and forecasting

The stationarity and autocorrelation properties of China's birth rate data were examined through autocorrelation function (ACF) and partial autocorrelation function (PACF) plots (Figure 5). The observed trailing patterns in both ACF and PACF plots confirmed the data's suitability

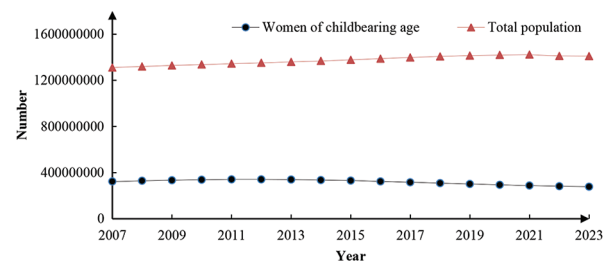


Figure 3. Trends in total population and women of childbearing age in mainland China

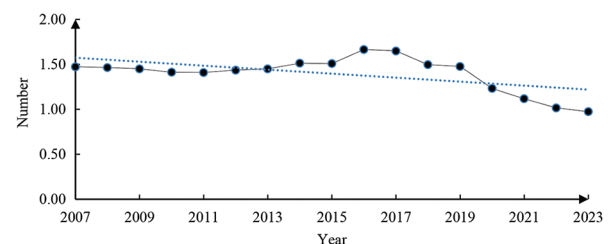


Figure 4. Average number of children born to women from 2007 to 2021

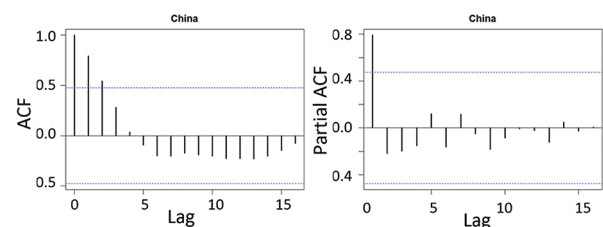


Figure 5. Autocorrelation and partial autocorrelation plots of birth rate data in mainland China
Abbreviation: ACF: Autocorrelation function.

for ARIMA modeling. Using the “auto.arima” function for optimal model selection, ARIMA(0,2,1) was identified as the most appropriate specification for China, featuring a statistically significant moving average coefficient ($ma1 = -0.579, p = 0.2743$).

Based on the selected optimal model and its parameters, we plotted the residual diagnostic results (Figure 6). The plot demonstrates three key characteristics: (i) residuals randomly fluctuate around the zero baseline, (ii) all ACF values at various lags fall within the blue dashed confidence boundaries, and (iii) residuals exhibit an approximately normal distribution. These diagnostic results confirm the model's statistical significance.

Furthermore, the model was validated using the Ljung-Box test, with AIC/BIC values calculated as shown in Table 1. For China's birth rate model, the p -value marginally exceeded 0.05, while the Q^* statistic was relatively large, and both AIC and BIC values were comparatively low. These results indicate that the model possesses statistically significant explanatory power, although with potential limitations in precision.

Following confirmation of the model's statistical validity, we employed it to forecast future birth rate trends. Using the same analytical framework applied to mainland China's birth rate data, we constructed and evaluated models for eight provinces, including Shanghai and Beijing. Table 1 presents: (i) the optimal ARIMA models identified by the “auto.arima” function for each province, (ii) the corresponding Ljung-Box test results, (iii) AIC/BIC values, and (iv) selected forecasting outcomes. Residual diagnostic plots for all eight provinces are provided in Figure A1.

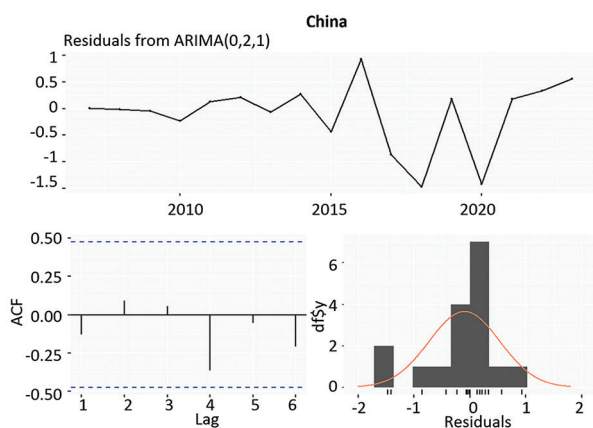


Figure 6. Residual diagnostic plots for the birth rate model in mainland China
Abbreviations: ACF: Autocorrelation function; ARIMA: Autoregressive integrated moving average.

Based on these province-specific ARIMA models, we projected birth rate trajectories through 2030, with results visualized in Figure 7.

Although the data analysis procedures and methodologies were consistent across provinces, the optimal ARIMA models for provincial birth rate data exhibited significant variation, reflecting distinct demographic characteristics.

For mainland China, the optimal birth rate model was ARIMA(0, 2, 1), indicating that the birth rate series required second-order differencing to achieve stationarity, and that short-term fluctuations were influenced by previous random disturbances. This suggests potential cumulative effects of policy interventions and a memory effect for abrupt demographic events in the national birth rate data.

For Shanghai and five other provinces, the optimal model was ARIMA(0, 1, 0), demonstrating no short-term autocorrelation and relatively stable birth rate trends. This pattern implies that birth rates in these provinces are less susceptible to short-term shocks (e.g., sudden policy changes or natural disasters).

Guangdong's optimal model, ARIMA(1, 0, 0), revealed stationary birth rates, with current rates determined by the previous year's values and random shocks. This reflects the influence of social inertia (e.g., persistent fertility attitudes and economic development). This characteristic can also indirectly explain the underlying drivers of Guangdong's population dynamics, specifically the decline in birth rates from 2007 to 2014, followed by a rapid increase during 2014 – 2016.

Hunan's ARIMA(2, 2, 0) model showed a non-stationary series requiring second-order differencing, with the current birth rates correlated with 2-year lags. This suggests delayed responses to external stimuli (e.g., policy changes).

While all models passed significance testing (though marginally in some cases), weaker significance levels may stem from external interference (e.g., policy or economic shocks). A critical limitation of ARIMA modeling warrants emphasis: its exclusive reliance on historical birth rate data and exclusion of external covariates, including policy reforms, technological advancements, and socioeconomic development. Consequently, while ARIMA provides valid short-term projections, predictive accuracy degrades progressively with longer forecast horizons.

China's birth rates are projected to continue declining, potentially falling below 5%. Even with additional government incentives, the birth rates are unlikely to

Table 1. Statistical significance testing and key predictive metrics of autoregressive integrated moving average (ARIMA) models

Area	ARIMA model	Ljung-Box test			AIC	BIC	Year	Point forecast	Lower (95%)	Upper (95%)
		Q*	df	p-value						
China	(0,2,1)	3.884	3	0.274	34.77	36.19	2024	5.68	4.33	7.03
							2025	4.98	2.63	7.32
							2026	4.27	0.85	7.69
Shanghai	(0,1,0)	1.974	3	0.5778	53.51	54.28	2024	3.95	1.578	6.322
							2025	3.95	0.596	7.304
							2026	3.95	-	8.058
Beijing	(0,1,0)	4.476	3	0.2144	42.57	43.34	2024	5.63	3.945	7.315
							2025	5.63	3.247	8.013
							2026	5.63	2.712	8.548
Hunan	(2,2,0)	5.847	3	0.119	11.09	13.22	2024	6.161	5.5778	6.745
							2025	6.373	4.563	8.182
							2026	6.447	2.876	10.017
Guangdong	(1,0,0)	5.908	3	0.116	52.92	55.42	2024	8.607	6.663	10.551
							2025	9.003	6.498	11.508
							2026	9.325	6.510	12.141
Hainan	(0,1,0)	5.119	3	0.163	40.84	42.39	2024	8.946	7.397	10.495
							2025	8.612	6.422	10.803
							2026	8.279	5.596	10.961
Xinjiang	(0,1,0)	1.144	3	0.767	58.38	59.8	2023	5.846	2.838	8.854
							2024	5.162	0.908	9.416
							2025	4.478	-	9.688
							2026	3.794	-	9.810
Heilongjiang	(0,1,0)	0.971	3	0.808	21.32	21.93	2023	3.037	1.998	4.076
							2024	2.735	1.266	4.204
							2025	2.432	0.633	4.231
							2026	2.129	0.052	4.207
Hebei	(0,1,0)	0.424	3	0.928	49.69	50.39	2023	6.09	3.765	8.415
							2024	6.09	2.803	9.377
							2025	6.09	2.064	10.116
							2026	6.09	1.441	10.739

Abbreviations: AIC: Akaike Information Criterion; BIC: Bayesian Information Criterion.

exceed 10‰, highlighting the persistent demographic challenges. Of the eight provinces examined, only Hunan and Guangdong demonstrate prospects for modest birth rate increases in the coming years, although with limited growth potential. Conversely, metropolitan areas including Shanghai and Beijing are anticipated to sustain depressed fertility levels or experience further reductions. Notably, Shanghai (below 4‰) and Heilongjiang (below 3‰) exhibit the most subdued birth rates, while Guangdong (below 10‰) and Hainan (below 9‰) register as the highest. These pronounced geographical variations underscore the heterogeneous demographic landscape across mainland

China and emphasize the necessity for customized policy measures responsive to localized reproductive dynamics.

4. Discussion

This study utilized authoritative statistical data from official sources in mainland China and selected provinces, employing the Joinpoint model to assess the effects of various family planning policy adjustments on birth rates. To investigate the underlying causes of China's declining fertility, we obtained childbearing-age female population data from GBD2021 and computed the average birth rate per woman. Furthermore, we implemented the ARIMA

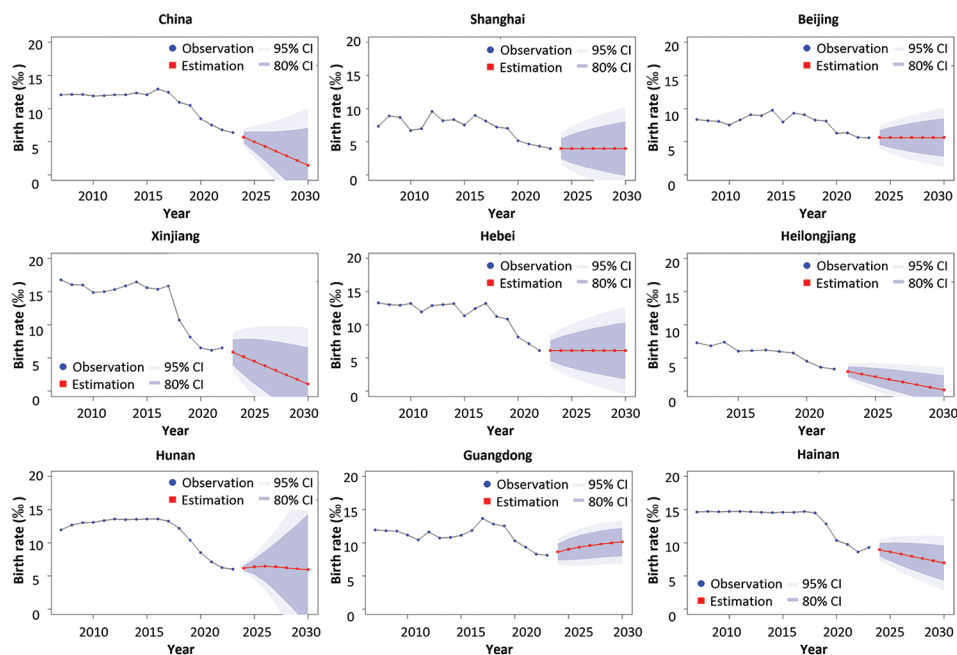


Figure 7. Trend forecast of birth rates in mainland China and eight provinces

model to forecast birth rate trends through 2030, providing insights for future family planning policy formulation.

Statistical analysis of data from 2007 to 2022 reveals a striking 44.05% decline in national birth rate (from 12.1‰ to 6.77‰), with provincial variations demonstrating clear spatial patterns – coastal provinces like Guangdong (30.60% decline) showed more moderate decreases compared to western provinces like Xinjiang (61.11% drop), while northeastern industrial zones (e.g., Heilongjiang: 54.25%) exhibited accelerated declines following local economic restructuring. Although the 2011 – 2015 policy adjustments generated temporary fluctuations – most notably a 7.1% rebound following the 2015 universal two-child policy – post-2016 trends show remarkably consistent linear declines, averaging 8.3% annually. The comprehensive three-child policy implemented in 2021 failed to reverse the persistent decline in birth rates, serving only to modestly mitigate the downward trend.

The Joinpoint analysis reveals that between 2010 and 2021, successive modifications to China's family planning policy temporarily stimulated birth rates. Each policy intervention produced a short-term fertility increase, though this primarily reflected a concentration of pent-up demand among eligible families rather than a fundamental shift in reproductive preferences (Lv *et al.*, 2025; Qi *et al.*, 2016; Zhang, 2025). Among the four major policy changes, the 2015 universal two-child policy demonstrated the most pronounced impact, while the 2021 three-child policy merely attenuated, without reversing, the ongoing fertility

decline. The significant but temporary fertility rebound following the 2015 universal two-child policy indicates that a subset of Chinese families remained willing to have two children. In contrast, the markedly weaker response to the 2021 three-child policy suggests that only a minimal proportion of families have any inclination toward three-child households. From a pessimistic perspective, the birth rate data from 2011 to 2023 incorporate short-term artificial boosts induced by policy adjustments, indicating that the underlying fertility challenges are substantially more severe than the raw statistics superficially suggest. These observations lead to a critical demographic projection: barring substantial changes to socioeconomic conditions or family support systems, China's birth rate is unlikely to experience meaningful recovery, even with complete deregulation of birth limits.

Two principal interlinked factors account for China's precipitous birth rate reduction: (i) a substantial demographic contraction in the core childbearing-age population, and (ii) a profound sociocultural shift in fertility intentions across generations. From 2007 to 2023, China's reproductive-age cohort (20 – 49 years) decreased steadily at an average annual rate of 2.67 million, with the most fertile subgroup (25 – 29 years) shrinking by 38%. Concurrently, the mean number of children per woman declined from 1.47 to 0.97 (a 34% decrease), reflecting reduced fertility intentions. Moreover, China's total population grew by 7% between 2007 and 2023, further amplifying the relative decline in birth rates. Thus, China's

persistent decline in birth rates fundamentally reflects the compounded effects of (i) demographic structural shifts, (ii) evolving fertility attitudes, and (iii) policy constraints. The reduction in the childbearing-age population will persist as an irreversible reality, exerting sustained downward pressure on birth rates. To maintain sustainable social development, the Chinese government must implement targeted interventions to elevate fertility intentions among the population.

The heterogeneity of ARIMA models constructed from 2007 – 2023 birth rate data reveals significant geographical disparities in both provincial fertility levels and responsiveness to policy interventions. These variations likely stem from complex interactions among multiple factors: (i) differential implementation of family planning policies across provincial administrations, (ii) varying levels of economic development and associated opportunity costs of childrearing, (iii) persistent cultural norms regarding family size in rural versus urban areas, and (iv) dramatically different living cost pressures, particularly housing affordability – relationships that require further investigation through expanded longitudinal data collection and advanced modeling. Therefore, each province should adopt targeted measures based on its unique fertility characteristics, and the specific policy responses should be investigated and analyzed in conjunction with each province's actual conditions. It can be foreseen that Shanghai, Beijing, and other provinces modeled by ARIMA(0,1,0) are more sensitive to policy stimulus, showing quick but short-lived effects. In contrast, provinces like Hunan, modeled by ARIMA(2,2,0), and Guangdong, modeled by ARIMA (1,0,0), exhibit lower sensitivity to policy interventions, with delayed but potentially longer-lasting responses.

Based on the forecasting results of the ARIMA model, China's birth rate is expected to continue its downward trend. Beijing, Shanghai, and Hebei may maintain relatively stable birth rates, with fluctuations influenced by external stimuli; Guangdong and Hunan may experience slight increases, though the magnitude of growth will be limited. Meanwhile, Heilongjiang, Xinjiang, and Hainan are expected to see further declines in birth rates, presenting more severe challenges. Although the ARIMA model considers only the birth rate itself without accounting for other influencing factors (limiting the precision of the forecasts), the projected trends and their confidence intervals (80% CI and 95% CI) still hold practical significance. From an optimistic perspective, based on the upper bound of the 95% CI, there is a possibility that the birth rate could reverse its continuous decline before 2030. However, the likelihood of exceeding 10‰ remains

extremely low. Under the most optimistic scenario for provincial birth rate projections, most provinces (such as Xinjiang) would maintain birth rates around 10‰, while a few provinces and cities (like Guangdong and Hunan) could reach 15‰. Notably, Heilongjiang, currently exhibiting the lowest birth rate, is unlikely to exceed 5‰ even under the most favorable estimates. Conversely, viewed pessimistically, China's future birth rate may decline to an exceptionally low level. These findings reflect structural demographic shifts rather than temporary fluctuations, with profound implications for China's long-term population trajectory and socioeconomic development model. China's demographic challenges will become increasingly severe, raising serious concerns about whether social stability and sustainable development can be maintained.

This study analyzed the impact of adjustments to China's family planning policy from the perspective of changes in birth rate data, which introduces some limitations. First, the ARIMA model relies on linear assumptions and cannot effectively capture nonlinear relationships in data, making it less adaptable to non-stationary or noisy datasets. As the forecast horizon lengthens, prediction accuracy may gradually decline. Second, both the Joinpoint and ARIMA models do not consider confounding factors such as economic development, population migration, and age structure. This omission weakens model significance and reduces analytical accuracy. Third, the inability to collect comprehensive occurrence rate data hinders deeper investigation into the root causes underlying the persistent fertility decline in provinces like Heilongjiang. Fourth, the birth rate data released by the Chinese government and provincial authorities may be underestimated, which could also affect the accuracy of our analysis and forecasting results. In future research, we recommend collecting more comprehensive data related to the factors influencing birth rates, enabling more robust modeling and analysis. This would support the development of effective policy recommendations aimed at stimulating birth rate increases and promoting sustainable social development.

5. Conclusion

Looking ahead, China's birth rate is expected to remain persistently below the demographic warning threshold of 15‰. This trend coincides with the nation's accelerating demographic transition toward an aging society, as evidenced by rising mortality rates, from 7.18‰ in 2021 to 7.87‰ in 2023, with further increases anticipated. The sustained fertility decline presents substantial challenges to maintaining balanced population development and

calls for comprehensive policy responses from the Chinese government. Potential measures may include further adjustments to family planning policy, improvements to the childcare support system, and the implementation of tax incentives and subsidies.

For provinces already experiencing critically low fertility rates (e.g., Heilongjiang, Shanghai, and Beijing), localized interventions tailored to provincial socioeconomic conditions must complement national policy adjustments. Such geographically specific approaches are crucial for stabilizing these vulnerable demographic landscapes. Future investigations should prioritize a systematic examination of regionally distinct fertility determinants, enabling: (i) enhanced understanding of spatial demographic variations; (ii) evidence-based policy calibration; and (iii) more effective intervention strategies.

This research direction promises to yield actionable insights for developing nuanced, location-specific solutions to China's complex demographic challenges, ultimately supporting more balanced national population development.

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Conflict of interest

The authors declare that they have no competing interests.

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Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The relevant raw data for this study were obtained from the official websites of relevant Chinese government agencies, as follows: China National Bureau of Statistics (<https://www.stats.gov.cn/sj/tjgb/ndtjgb/>); Beijing Municipal Bureau of Statistics (https://tjj.beijing.gov.cn/tjsj_31433/tjgb_31445/ndgb_31446/); Guangdong Statistical Information Network (<http://stats.gd.gov.cn/tjgb/index.html>); Hainan Provincial People's Government (<https://en.hainan.gov.cn/hainan/ndsj/list3.shtml>); Hebei Provincial People's Government (<http://www.hebei.gov.cn/columns/3bbf017c-0e27-4cac-88c0-c5cac90ecd73/index.html>); Heilongjiang Provincial People's Government (<https://www.hlj.gov.cn/hlj/c108419/zfxgk.shtml>); Hunan Provincial People's Government (http://www.hunan.gov.cn/zfsj/tjgb/202403/t20240322_33262931.html); Shanghai Municipal Bureau of Statistics (<https://tjj.sh.gov.cn/tjgb/index.html>); and Statistical Bureau of Xinjiang Uygur Autonomous Region (<http://tjj.xinjiang.gov.cn/tjj/tjgn/ist.shtml>).

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Appendix

Table A1. Birth rate data (per 1,000 population) for mainland China and eight provinces

Year	Province								China
	Shanghai	Beijing	Xinjiang	Heilongjiang	Hebei	Hunan	Guangdong	Hainan	
2007	7.34	8.32	16.79	-	13.3	11.96	11.96	14.62	12.10
2008	8.89	8.17	16.05	-	13.04	12.68	11.8	14.71	12.14
2009	8.64	8.06	15.99	-	12.93	13.05	11.78	14.66	12.13
2010	6.70	7.5	14.85	-	13.22	13.10	11.18	14.71	11.90
2011	6.97	8.29	14.99	-	11.93	13.35	10.45	14.72	11.93
2012	9.56	9.05	15.32	7.3	12.88	13.58	11.60	14.66	12.10
2013	8.18	8.93	15.84	6.86	13.04	13.5	10.71	14.59	12.08
2014	8.35	9.75	16.44	7.37	13.18	13.52	10.8	14.56	12.37
2015	7.52	7.96	15.59	6.00	11.35	13.58	11.12	14.57	12.07
2016	9.00	9.32	15.34	6.12	12.42	13.57	11.85	14.57	12.95
2017	8.10	9.06	15.88	6.22	13.2	13.27	13.68	14.73	12.43
2018	7.20	8.24	10.69	5.98	11.26	12.19	12.79	14.48	10.94
2019	7.00	8.12	8.14	5.73	10.83	10.39	12.54	12.87	10.48
2020	5.14	6.30	6.53	4.50	8.16	8.53	10.28	10.36	8.50
2021	4.67	6.35	6.16	3.59	7.15	7.13	9.35	9.74	7.52
2022	4.35	5.67	6.53	3.34	6.09	6.23	8.30	8.60	6.77
2023	3.95	5.63	-	-	-	6.00	8.12	9.28	6.39

Note: “-” indicates that provincial birth rate data were not published. In the Joinpoint analysis, missing data were excluded. For ARIMA model construction: the models for Hebei and Xinjiang were built using data from 2007 to 2022 to predict the 2023 birth rate, while the model for Heilongjiang was based on data from 2012 to 2022 and also used to predict the 2023 birth rate.

Table A2. Population data for childbearing-age women in mainland China from 2007 to 2021

Year	Age range						Total
	20 – 24	25 – 29	30 – 34	35 – 39	40 – 44	45 – 49	
2007	57,673,318	46,110,944	53,832,358	60,808,029	65,253,210	39,501,056	323178915
2008	61,050,385	46,585,673	51,385,517	60,191,565	66,259,247	42,899,430	328371818
2009	63,241,219	48,043,709	49,363,450	59,352,937	66,226,203	47,438,854	333666372
2010	63,771,398	50,574,596	47,945,374	57,981,720	65,544,025	52,190,620	338007734
2011	62,361,114	54,104,685	46,997,382	55,909,221	65,578,053	56,450,084	341400539
2012	59,483,123	57,832,811	46,535,324	53,361,930	64,870,456	59,564,671	341648316
2013	55,657,362	60,891,359	46,811,977	50,751,746	64,679,220	61,025,458	339817122
2014	51,381,564	62,595,237	48,046,843	48,557,504	63,764,089	61,342,113	335687349
2015	47,236,816	62,495,359	50,315,428	46,959,344	62,683,718	60,986,963	330677627
2016	43,803,173	60,392,886	53,526,482	45,835,539	59,953,763	60,282,503	323794346
2017	41,046,417	56,913,274	56,890,882	45,207,075	56,726,036	59,530,157	316313840
2018	38,796,584	52,673,649	59,582,579	45,324,608	53,449,896	58,815,048	308642363
2019	36,938,727	48,211,700	60,971,351	46,402,935	50,829,410	57,872,003	301226125
2020	35,444,893	44,097,412	60,657,011	48,519,083	48,711,138	56,406,032	293835568
2021	34,306,654	40,866,334	58,469,485	51,597,150	47,977,697	54,260,079	287477400
2022	57,673,318	46,110,944	53,832,358	60,808,029	65,253,210	39,501,056	323178915
2023	61,050,385	46,585,673	51,385,517	60,191,565	66,259,247	42,899,430	328371818

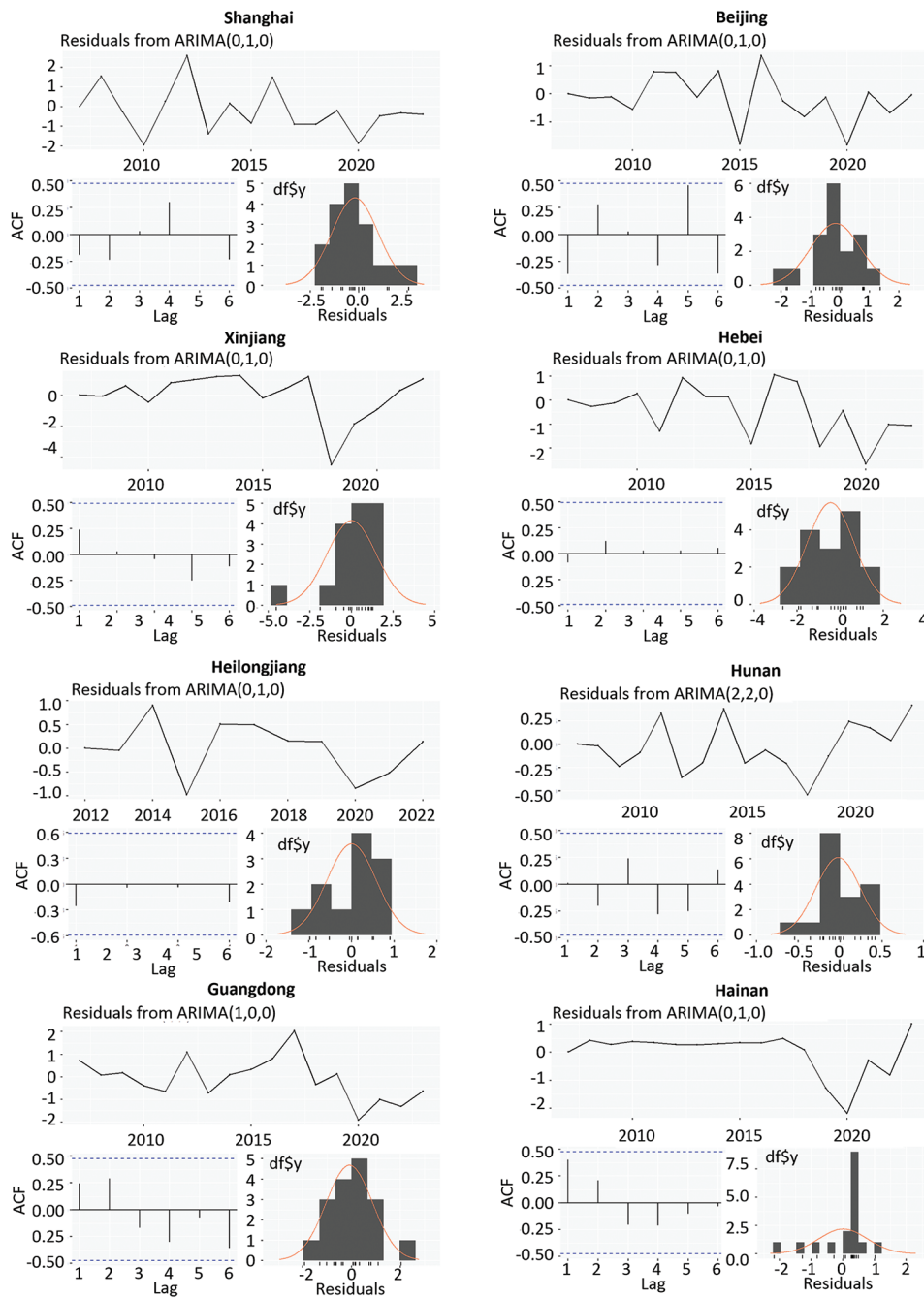


Figure A1. Residual diagnostics for birth rate models in eight Chinese provinces
Abbreviation: ARIMA: Autoregressive integrated moving average.