

Preplanned Studies

Birth Cohort Study on Longitudinal Impact of Internal Migration Status on Routine Vaccination Coverage in the First Three Years of Life — Beijing, China, 2021–2025

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Summary

What is already known about this topic?

High population mobility frequently undermines public health efforts to maintain immunization coverage, as mobile families often face barriers to accessing consistent healthcare.

What is added by this report?

Migration across provincial-level administrative divisions (PLADs) drives progressively widening coverage disparities while contributing to delayed vaccination and missed catch-up opportunities within the National Immunization Program (NIP) during the first three years of life in China.

What are the implications for public health practice?

These findings underscore the need for a dynamic, life-course approach to migrant child immunization, with heightened focus on ensuring coverage during infancy. Vaccination verification and catch-up efforts should be intensified at preschool enrollment.

and its temporal trends. Log-rank tests evaluated differences in timely and catch-up vaccination.

Results: The final cohort included 14,784 children (44.9% migrant; 55.1% local). Migrant children consistently had lower vaccination coverage at all time points: third dose of diphtheria, tetanus, and pertussis vaccine (DTP3) at 12 months (91.21% *vs.* 96.24%), second dose of measles, mumps, and rubella vaccine (MMR2) at 24 months (88.08% *vs.* 93.72%), and second dose of inactivated hepatitis A vaccine (HepA2) at 36 months (82.31% *vs.* 94.09%). GEE models revealed a more rapid decline in vaccination coverage among migrant children [adjusted odds ratio (aOR)=0.90, 95% confidence interval (CI): 0.82–0.98]. Timely and catch-up vaccination rates were also significantly lower in the migrant group.

Conclusions: Cross-PLAD migration status is a significant independent risk factor for lower routine vaccination coverage in early childhood, with gaps widening over time. These findings underscore the need for a dynamic, life-course approach to migrant child immunization.

ABSTRACT

Background: Evidence on how migration status affects vaccination coverage in early childhood remains limited.

Objective: To evaluate the impact of cross-PLAD migration status, defined by household registration at birth, on routine vaccination coverage over the first three years of life.

Methods: A birth cohort study was conducted using data from the Beijing Immunization Information System. Children born between April 1, 2021, and March 31, 2023, were followed until March 31, 2025. Cross-PLAD migrant status was defined by household registration at birth. Generalized estimating equations (GEE) assessed the impact of migration status on vaccination coverage at 12, 24, and 36 months of age

Under the World Health Assembly's Immunization Agenda 2030 (IA2030), global initiatives strive to ensure that everyone, everywhere, fully benefits from vaccines (1). Yet population mobility continues to challenge these public health goals (2). Internal migration within many countries far exceeds international migration in scale (3), and despite this massive demographic shift, vaccination coverage among internal migrant children has not been comprehensively evaluated.

The relationship between vaccination coverage and migration status involves complex dynamics (4). However, the existing literature consists predominantly of cross-sectional studies that provide only a snapshot

of coverage at a single time point, leaving unclear how internal migration status dynamically influences vaccination trajectories during the critical preschool years. Furthermore, assessments of vaccination timeliness and catch-up efforts are often absent from studies of migrant populations. Many existing studies on vaccination coverage among internal migrants are also constrained by small sample sizes, rendering them susceptible to selection bias.

Driven by rapid socioeconomic development, China has experienced unprecedented internal population migration in recent decades (5). As the national political, economic, and cultural hub, Beijing has attracted a vast influx of migrants, creating significant public health challenges from the rapidly growing population of migrant children. Unlike internal migration in many other national contexts, residing in Beijing without local household registration entails not only geographic relocation but also an "institutional identity transition," as access to social support systems and public health services is frequently tied to an individual's household registration status. This study leveraged a population-based birth cohort in Beijing to evaluate how cross-PLAD migration status, defined by household registration, influences routine vaccination coverage during the first 36 months of life and to characterize the longitudinal trends of this impact across early childhood.

This study was conducted in Beijing, China's capital, and enrolled participants from all 17 administrative districts. Beijing comprised approximately 180,000 eligible children per age group. Migrant children were classified based on their household registration (Hukou) status at the time of birth. Under Beijing's strictly managed household registration system, a child receives an ID number starting with "11" only if at least one parent holds Beijing household registration at birth. For children without Beijing household registration, parents must coordinate with their PLAD of origin to process household registration at the local police station, register the child's name, and obtain a citizen ID number. Only after securing this ID can the child be enrolled in a Beijing vaccination clinic and integrated into the immunization information system for standardized vaccination services.

Children holding Beijing household registration at birth were categorized as the local population, whereas those registered in other PLADs were classified as cross-PLAD migrants. This classification reflects not only physical relocation but also a state of

"administrative migration" at birth.

The cohort was established using data from the Beijing Immunization Information System (IIS), which captured comprehensive data including pediatric names, birth years, vaccine types, dosages, administration dates, management status, clinic information, and guardian demographics. In compliance with China's immunization information collection standards, vaccination data from all PLADs must be uploaded promptly via PLAD-level data exchange platforms. Consequently, for children who migrated between Beijing and other PLADs, vaccination records were supplemented through this cross-PLAD data exchange mechanism.

A sample size of 1,606 per group provided 90.0% power to detect an odds ratio of 0.68, based on a repeated-measures design with two time points and a compound symmetry covariance structure. The calculation assumed a vaccination proportion of 0.90 in the migrant group, a within-subject correlation of 0.80, and a significance level of 0.05. Recognizing that detecting an interaction effect typically requires substantially greater statistical power than assessing main effects alone, we applied a fourfold larger sample to ensure robust detection of both primary and interaction effects.

Eligibility criteria included birth between April 1, 2021, and March 31, 2023, current residence in Beijing for more than two months, and willingness to participate as demonstrated by written informed consent at enrollment in the IIS. The total eligible population in the Beijing Immunization Information System was 293,984. Using a stratified systematic sampling method based on birth month, we initially identified 15,134 children born between April 1, 2021, and March 31, 2023. Children with incomplete or inaccurate demographic and vaccination records were excluded. After removing 350 records due to missing guardian ID numbers ($n=115$), lack of demographic data ($n=74$), erroneous information ($n=146$), or duplication ($n=15$), the final cohort consisted of 14,784 children. The study was adequately powered. The total population was 293,984, and there were no statistical differences in demographic indicators between the sampled group and the total population.

This study employed a birth cohort design with multiple longitudinal measurement endpoints. A total of 14,784 children born between April 1, 2021, and March 31, 2023, were enrolled. Follow-up commenced at birth (0 months of age), and the study period ended on March 31, 2025.

The third dose of diphtheria, tetanus, and pertussis vaccine (DTP3), the second dose of measles, mumps, and rubella vaccine (MMR2), and the second dose of inactivated hepatitis A vaccine (HepA2) served as indicator vaccines. These are routinely administered at 5 months (or as early as 4 months for pentavalent vaccine recipients), 18 months, and 24 months of age, respectively, making them suitable for longitudinal assessment of vaccination coverage from birth to 36 months. The study population was grouped by birth date to ensure complete follow-up for each vaccine schedule: 1) children born from April 2022 to March 2023 ($n=7,218$; aged 24–35 months at study conclusion), with coverage assessed for DTP3 at 12 months and MMR2 at 24 months; and 2) children born from April 2021 to March 2022 ($n=7,566$; aged 36–47 months), with coverage assessed for DTP3 at 12 months and HepA2 at 36 months. Timely vaccination was evaluated across three intervals: 4–6, 18–19, and 24–25 months for DTP3 (all participants), MMR2 (the 2022–2023 birth group), and HepA2 (the 2021–2022 birth group), respectively. Catch-up vaccination was defined as the administration of vaccine doses to children who missed the recommended schedule, in accordance with the Guidelines for Immunization Procedures and Notes for Children of the National Immunization Program (2021 Edition) issued by the National Health Commission of China. Catch-up rates were measured across three intervals: 13–18 months for DTP3 (all participants), 25–30 months for MMR2 (the 2022–2023 birth group), and 37–42 months for HepA2 (the 2021–2022 birth group). This approach ensured that each child had a complete observation window for their respective vaccination milestones. Children who did not receive the indicator vaccines by the end of follow-up, as well as those who died prior to vaccination, were treated as right-censored. Data on vaccinations administered outside Beijing were fully retrieved through cross-PLAD immunization data exchange interfaces, ensuring cohort completeness with no loss to follow-up.

In this cohort study, children were longitudinally evaluated from 12 to 36 months of age to monitor vaccination coverage for DTP3, MMR2, and HepA2.

Generalized estimating equations (GEE) evaluated the longitudinal impact of cross-PLAD migrant status, time trend, and their interaction on vaccination coverage during the first 36 months of life. Kaplan-Meier curves estimated the cumulative probability of

timely vaccination among age-eligible children, defined as receipt of DTP3, MMR2, or HepA2 within one to two months of the recommended age. For the Kaplan-Meier analysis, the start time was defined as the age at which each indicator vaccine was first recommended. Follow-up ended at the earliest of the following: the actual date of vaccination, the date of death, or the end of the predefined observation window. Differences between migrant status groups were compared using the log-rank test. The same approach was applied to estimate the cumulative probability of catch-up vaccination among children who had missed their initial doses.

Statistical significance was defined as a two-sided $P \leq 0.05$. All analyses were performed using R software (version 4.5.1; R Foundation for Statistical Computing, Vienna, Austria).

Among the 14,784 participants, 51.2% (7,566) were aged 36–47 months at the time of the survey, 49.3% (7,290) were born in 2022, 52.3% (7,725) were male, 75.5% (11,161) were firstborn children, and 93.3% (13,796) were of Han ethnicity. Additionally, 23.9% (3,539) of mothers held Beijing household registration, 35.8% (5,297) were aged 30–34 years, and 52.0% (7,686) of families lived in suburban districts. No differences between local-registered and cross-PLAD migrant children were observed in age, birth year, or sex (all $P > 0.05$), whereas significant differences were found in birth order, ethnicity, maternal household registration, maternal age, and residential district (all $P < 0.05$) (Table 1).

At 12, 24, and 36 months, vaccination coverage was consistently higher among local-registered children than among PLAD-level migrant children for DTP3 (96.24% *vs.* 91.21%), MMR2 (93.72% *vs.* 88.08%), and HepA2 (94.09% *vs.* 82.31%), respectively (Figure 1).

The follow-up analysis comprised 29,568 observations, with an overall vaccination coverage of 91.98% (27,197/29,568). Both univariate and multivariate GEE models revealed significant associations between migrant status, time trend, their interaction, and vaccination coverage. After adjusting for potential confounders, migrant children (88.19%; 11,717/13,286) had significantly lower odds of vaccination than local children (95.07%; 15,480/16,282), with an adjusted odds ratio (aOR) of 0.51 [95% confidence interval (CI): 0.41, 0.63] at 12 months. Over the 36-month period, the odds of vaccination among local children declined by an average of 25% ($OR=0.75$; 95% CI: 0.70, 0.80) per

TABLE 1. Baseline characteristics of resident children categorized by migration status.

Variable	Total	Migration Status		χ^2	P
		Local-registered children	Provincial-migrant children		
Total	14,784 (100.0)	8,141 (100.0)	6,643 (100.0)		
Age at survey (months)				0.18	0.675
24–35	7,218 (48.8)	3,962 (48.7)	3,256 (49.0)		
36–47	7,566 (51.2)	4,179 (51.3)	3,387 (51.0)		
Birth year				1.22	0.544
2021	5,673 (38.4)	3,127 (38.4)	2,546 (38.3)		
2022	7,290 (49.3)	3,991 (49.0)	3,299 (49.7)		
2023	1,821 (12.3)	1,023 (12.6)	798 (12.0)		
Gender				1.33	0.248
Female	7,059 (47.7)	3,922 (48.2)	3,137 (47.2)		
Male	7,725 (52.3)	4,219 (51.8)	3,506 (52.8)		
Birth order				93.42	<0.001
First child	11,161 (75.5)	5,931 (72.9)	5,230 (78.7)		
Second child	3,315 (22.4)	2,064 (25.4)	1,251 (18.8)		
Third child or higher	308 (2.1)	146 (1.8)	162 (2.4)		
Ethnicity				35.46	<0.001
Han	13,796 (93.3)	7,507 (92.2)	6,289 (94.7)		
Other minorities	988 (6.7)	634 (7.8)	354 (5.3)		
Maternal household registration				3772.80	<0.001
Beijing	3,539 (23.9)	3,534 (43.4)	5 (0.1)		
Other PLADs	11,245 (76.1)	4,607 (56.6)	6,638 (99.9)		
Maternal age (years)				684.71	<0.001
18–29	1,204 (8.1)	367 (4.5)	837 (12.6)		
30–34	5,297 (35.8)	2,537 (31.2)	2,760 (41.5)		
35–39	6,075 (41.1)	3,689 (45.3)	2,386 (35.9)		
≥40	2,208 (14.9)	1,548 (19.0)	660 (9.9)		
Residential district				163.94	<0.001
Urban area	7,098 (48.0)	4,295 (52.8)	2,803 (42.2)		
Suburban area	7,686 (52.0)	3,846 (47.2)	3,840 (57.8)		

Note: Data are presented as No. (%).

Abbreviation: PLAD=provincial-level administrative division.

12-month interval. Migrant children experienced a more rapid decline in vaccination coverage over time, with an interaction *OR* of 0.90 (95% *CI*: 0.82, 0.98) relative to the rate of decline in local children (Table 2).

By 6 months of age, 71.40% of age-eligible local children had received timely DTP3 vaccination, compared with 55.59% of migrant children. Similarly, by 19 months, 72.08% of local children had received timely MMR2 vaccination, versus 61.76% of migrant children. For HepA2 by 25 months, the proportion

was 38.16% among local children compared with 28.16% among migrant children (Figure 2).

Among children aged 13–18 months, 33.00% of age-eligible local children received DTP3 catch-up vaccination, compared with 24.74% of migrant children. In the 25–30 month age group, 29.27% of local children received MMR2 catch-up vaccination, versus 15.55% of migrant children. For HepA2 in the 37–42 month age group, the catch-up rate was 8.66% among local children compared with 5.28% among migrant children (Figure 3).

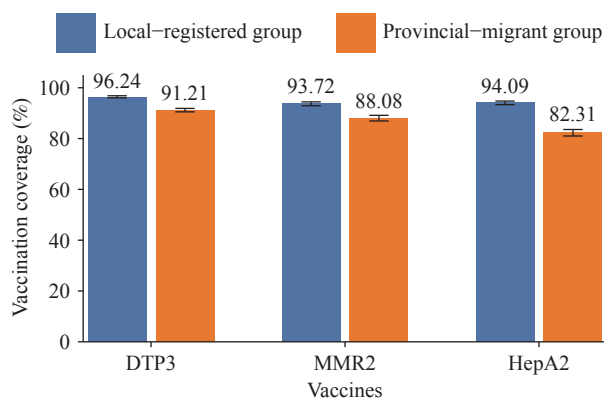


FIGURE 1. Vaccination proportions for DTP3, MMR2, and HepA2 by migration status from 12 to 36 months of age. Abbreviation: DTP3=third dose of diphtheria, tetanus, and pertussis vaccine; MMR2=second dose of measles, mumps, and rubella vaccine; HepA2=second dose of inactivated hepatitis A vaccine.

DISCUSSION

This study represents a pioneering effort following China's integration of PLAD-level vaccination data into the National Immunization Information System, a process initiated in 2022. It also marks the first assessment of vaccination coverage utilizing nationwide data since the implementation of the cross-PLAD vaccination data inquiry interface in 2024. These findings carry significant public health implications, underscoring the urgent need to implement cross-PLAD data exchange protocols to optimize vaccination management.

This longitudinal cohort study provides the first evidence that cross-PLAD migration status drives progressively widening coverage disparities while also contributing to delayed vaccination and missed catch-up opportunities within the NIP during the first three years of life.

Consistent with global evidence on migrant health vulnerabilities (6), PLAD-level migrant children in Beijing had significantly lower routine vaccination coverage compared with local peers. Crucially, this gap widened over time — from approximately 5 percentage points (DTP3) at 12 months to over 11 points (HepA2) at 36 months. While most prior studies rely on cross-sectional or single-time assessments, our longitudinal design with repeated evaluations uniquely reveals this dynamic disadvantage, demonstrating that vaccination likelihood declined more rapidly for migrant children — a pattern of "starting behind and falling back faster." Potential drivers include mobility-induced disruptions to health records and appointment

reminders, inconsistencies in NIP vaccine schedules across PLADs, and possibly waning parental engagement as children age (7).

Disparities extended beyond cumulative coverage to timely vaccination. For instance, the timely DTP3 vaccination gap reached nearly 16 percentage points. Lower timeliness delays protection and suggests practical barriers for migrant families, such as lack of schedule awareness or difficulty accessing services (8). Furthermore, catch-up vaccination rates after missed doses were significantly lower among migrant children, indicating that follow-up systems fail to effectively reach this high-risk group and that early delays translate into persistent immunity gaps (9–10).

These findings call for a dynamic, life-course approach to migrant child immunization, with intensified focus on continuity between 12 and 36 months. System improvements should include establishing seamless inter-regional digital health records, implementing mobile vaccination reminders and scheduling tools, and enhancing training for community health workers to deliver proactive health education and follow-up for age-appropriate children. Targeted health promotion is essential to sustain vaccination willingness as children age. Vaccination verification and catch-up efforts should be emphasized at preschool enrollment.

Several limitations warrant attention. First, our operational definition of "PLAD-level migrant" relied on non-local household registration — a criterion that captures migration status at birth but may not fully reflect subsequent mobility. Internal data suggest that the under-vaccination rate among those with cross-PLAD records is higher than reported in this birth cohort. Misclassification bias would likely lead to an underestimation of the true disparity between local and migrant children; therefore, our findings represent a conservative estimate of the impact of migration status on vaccination coverage. Second, as an observational cohort study, it may have omitted relevant confounders, such as guardians' educational attainment and household income. Third, the use of a recent sample from Beijing may introduce selection bias, and findings may not be generalizable to the entire Chinese population. Fourth, MMR2 was selected for the 2022–2023 cohort and HepA2 for the 2021–2022 cohort. While this design optimizes longitudinal clarity and minimizes data redundancy, it may reduce the effective sample size for specific vaccine analyses.

In conclusion, this longitudinal study demonstrates that cross-PLAD migration status is a key independent

TABLE 2. Longitudinal impact of provincial migrant status, time trend, and their interaction on vaccination coverage over the first 36 months of life.

Variables	No. of children	No. of vaccination	Coverage (%)	Univariate analysis		Multivariate analysis	
				OR (95% CI)	P	aOR (95% CI)	P
Total	29,568	27,197	91.98				
Migration Status							
Local-registered children	16,282	15,480	95.07	ref		ref	
Provincial migrant children	13,286	11,717	88.19	0.48 (0.39, 0.59)	<0.001	0.51 (0.41, 0.63)	<0.001
Time				0.76 (0.71, 0.81)	<0.001	0.75 (0.70, 0.80)	<0.001
Migration Status × Time				0.90 (0.82, 0.97)	0.010	0.90 (0.82, 0.98)	0.012

Note: Odds ratios were calculated using both univariate and multivariate GEE regression analyses, adjusted for birth year, sex, birth order, ethnicity, maternal household registration status, maternal age, and residential district. The time trend effect refers to the change in vaccination coverage as individuals age, evaluated at three time points in the model: 12, 24, and 36 months. The interaction term Migration Status × Time was tested in GEE regression analyses.

Abbreviation: OR=odds ratio; aOR=adjusted odds ratio; CI=confidence interval; GEE=generalized estimating equations.

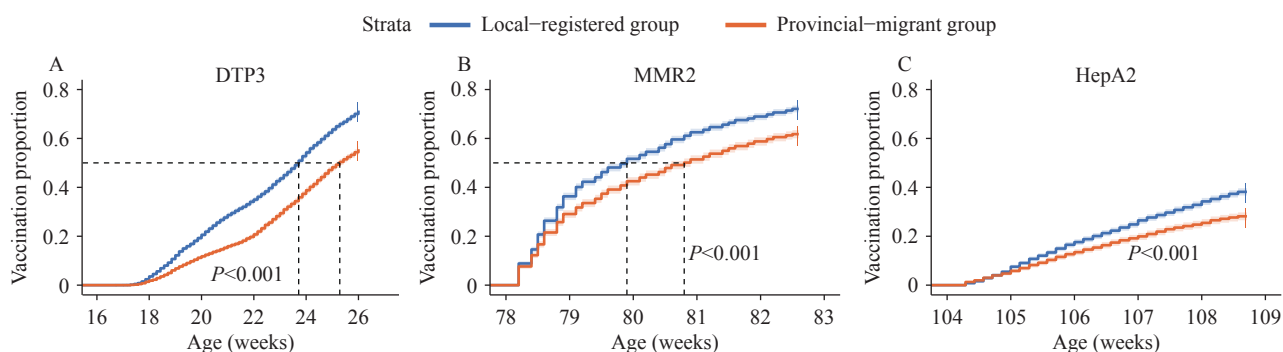


FIGURE 2. Timely vaccination rates by migration status and age. (A) DTP3 timely vaccination rate. (B) MMR2 timely vaccination rate. (C) HepA2 timely vaccination rate.

Note: Kaplan-Meier curves display cumulative vaccination rates for DTP3, MMR2, and HepA2 within one to two months of age eligibility, stratified by migration status. Group differences were assessed using the log-rank test.

Abbreviation: DTP3=third dose of diphtheria, tetanus, and pertussis vaccine; MMR2=second dose of measles, mumps, and rubella vaccine; HepA2=second dose of inactivated hepatitis A vaccine.

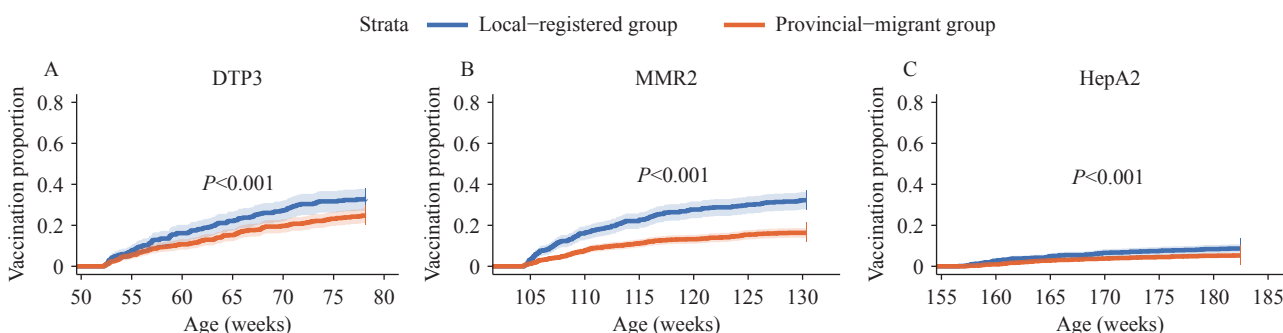


FIGURE 3. Catch-up vaccination rates by migration status and age. (A) DTP3 catch-up vaccination rate. (B) MMR2 catch-up vaccination rate. (C) HepA2 catch-up vaccination rate.

Note: Kaplan-Meier curves display cumulative catch-up vaccination rates for DTP3, MMR2, and HepA2 within the age groups of 13–18 months, 25–30 months, and 37–42 months, respectively, stratified by migration status. Group differences were assessed using the log-rank test.

Abbreviation: DTP3=third dose of diphtheria, tetanus, and pertussis vaccine; MMR2=second dose of measles, mumps, and rubella vaccine; HepA2=second dose of inactivated hepatitis A vaccine.

factor driving lower early childhood vaccination coverage, with gaps widening significantly over time. Migrant children also experienced delayed vaccination and missed catch-up opportunities within the NIP during the first three years of life. These findings provide a crucial evidence base for targeted, continuous interventions to protect migrant children and advance equitable immunization coverage.

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