

Article

How Does Internal Migration Affect Beijing–Tianjin–Hebei Cities?

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Abstract: As China’s regional development enters a critical stage of population redistribution and urban transformation, the impact of population mobility on regional demographic structures and urban functional restructuring has become increasingly prominent. Against this backdrop of accelerating Beijing–Tianjin–Hebei integration, cities of varying types have been confronted with growing complexity in demographic transitions and socioeconomic stratification during their processes of absorbing or exporting populations. This study employed microdata from the National Bureau of Statistics to construct migration flow matrices and utilized a decomposition quantification approach to explore the impact of internal migration on the population structure and quality in 13 cities within the Beijing–Tianjin–Hebei region. The findings indicated that, while Beijing has achieved some success in population control, it overall exhibits a “large inflow and large outflow” pattern. Langfang has attracted a large number of highly educated individuals and male migrants under the spillover effect from Beijing. Shijiazhuang’s population attractiveness has increased, yet the outflow of highly educated individuals remains unmitigated. Meanwhile, the internal migrant structures in industrial cities such as Tianjin and Tangshan have undergone significant changes following the industrial transformation. Cities in the passive outflow area and agricultural transformation area have experienced siphoning effects, but they face different potential risks due to their unique characteristics. This study further enriches the understanding of the impact mechanisms underlying domestic population mobility and provides differentiated policy references for cities to reconcile their development objectives with demographic realities.



Academic Editors: Jianming Cai,
Agnieszka Sompolska-Rzechuła,
Anna Oleńczuk-Paszal,
Monika Śpiewak-Szyjka and
Małgorzata Blaszkę

Received: 3 March 2025

Revised: 6 May 2025

Accepted: 23 May 2025

Published: 28 May 2025

Citation: Mi, H.; Zheng, Y. How Does Internal Migration Affect Beijing–Tianjin–Hebei Cities? *Sustainability* **2025**, *17*, 4959. <https://doi.org/10.3390/su17114959>

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Keywords: internal migration; demographic changes; population structure; Beijing–Tianjin–Hebei coordinated development

1. Introduction

Internal migration refers to the movement of people across administrative units within a country or region, which significantly impacts the geographic redistribution of population characteristics. This phenomenon is closely related to regional economic and social attributes, the stage of urban development, and policy orientations [1–3]. Currently, China is undergoing a transition characterized by aging, the fertility rate declining, and the demographic dividend gradually diminishing. The country may enter a long-term phase of population decline, where migration is likely to replace birth and death rates as a critical factor influencing regional population growth or reduction [4–6]. Therefore, analyzing the effects and changes brought by internal migration on population characteristics is not only theoretically significant for understanding regional population dynamics but also practically crucial for developing industrial planning and promoting sustainable regional development [7].

From the perspective of economic development, internal migration has reshaped regional comparative advantages and factor endowment structures. Inflow cities like Beijing and Tianjin leverage agglomeration effects to drive industrial specialization, technological spillovers, and service sector expansion, thereby enhancing economic efficiency and meeting increasingly diversified labor market demands [8–10]. Conversely, peripheral cities in Hebei, as outflow cities, may temporarily alleviate employment pressures through remittance income, yet face long-term challenges of hollowing out and aging acceleration due to a youth labor exodus, ultimately undermining the sustainable development potential [11,12]. Notably, the emerging return migration trends driven by metropolitan functional decentralization and industrial restructuring demonstrate significant educational selectivity and spatial heterogeneity in relocation patterns [13–15], highlighting the necessity for further investigation into the structural transformations of population mobility.

According to the National Economic and Social Development Statistical Bulletin, by the end of 2023, the permanent population in the Beijing–Tianjin–Hebei (BTH) region reached 109 million, accounting for 7.76% of China’s total population and making it the third-largest population-dense area in the country [16]. Before 2014, the industrial structure of this region was predominantly characterized by large-scale heavy industries, resulting in severe air pollution, a low resource allocation efficiency, and an imbalanced pattern of population concentration towards Beijing and Tianjin [17,18].

With the implementation of the Beijing–Tianjin–Hebei coordinated development strategy by the central government, this region has gradually reduced its proportion of traditional heavy industries and high-pollution sectors. It intends to foster more modern service industries, high-end manufacturing industries, and high-tech industries. In conjunction with the restructuring of the industrial landscape, the patterns of internal migration have also undergone notable shifts [19]. The populations of Beijing and Tianjin have exhibited a downward trend since 2017 and 2016, respectively, effectively maintaining a population of less than 23 million in Beijing [20,21]. In conjunction with the restructuring of the industrial landscape, the patterns of internal migration have also undergone notable shifts [22,23]. As Hebei Province has yet to establish a central city to accommodate the dispersed population from Beijing and Tianjin, over 30% of the total population remains concentrated in these two megacities. The uneven patterns of internal migration serve to illustrate the challenges encountered during the implementation phase [24].

Meanwhile, the BTH region’s coordinated development strategy has entered an advanced implementation phase, with the region reconstructing its developmental framework through strategic differentiation. Beijing has adopted a “streamlining” approach as its core strategy, prioritizing the relocation of non-capital functions while cultivating new growth drivers in advanced industries. Tianjin is pursuing a “competitive advantage enhancement” pathway, strengthening its role as an international gateway hub and optimizing the resource allocation efficiency. Hebei is focusing on “bridging development gaps” by systematically absorbing industrial transfers and redistributing the population to stimulate endogenous growth momentum. Through institutional innovations encompassing transportation interconnectivity, joint ecological governance, and industrial collaboration mechanisms, the tri-region system is advancing population mobility and factor allocation optimization, ultimately aiming to establish a highly integrated and balanced regional framework characterized by efficiency and coordination (Figure 1).

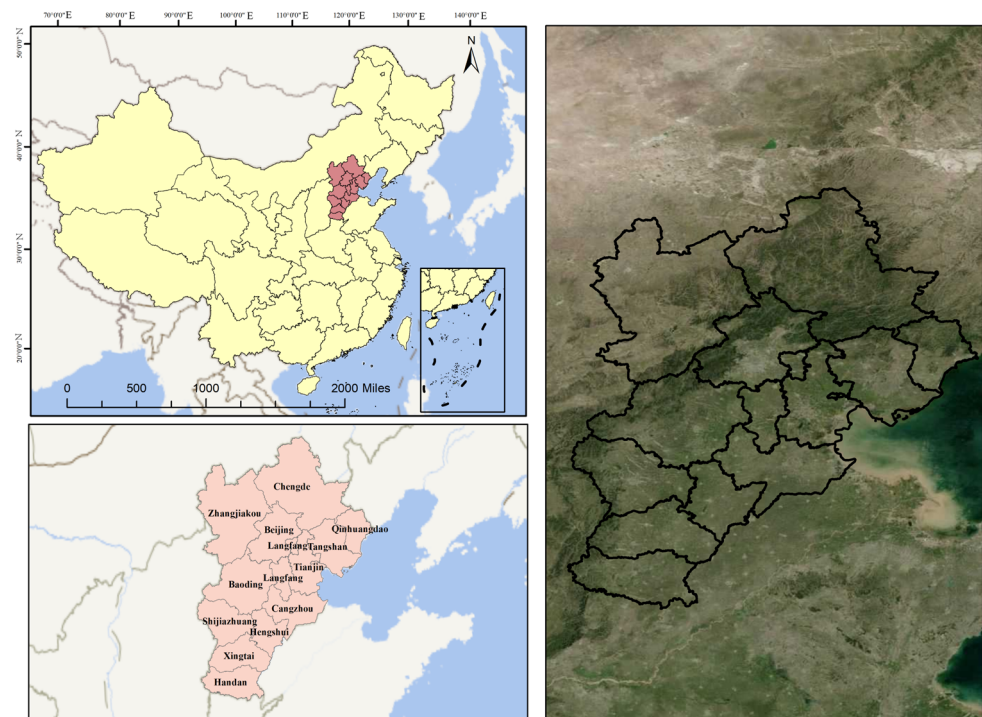


Figure 1. Beijing–Tianjin–Hebei region map and remote sensing images. The top-left panel shows the location of the BTH region (in red) within China (in yellow). The bottom-left panel marks the positions of BTH cities. The right panel displays the topography of the BTH region. Data source: National Platform for Common GeoSpatial Information Services. Map content approval number: GS (2024) 0650.

However, optimizing the population structure requires sustained policy guidance and structural adjustment measures. To effectively promote the rational spatial distribution and functional alignment of the population in the BTH region, it is essential to systematically monitor and assess the dynamic changes in key demographic indicators such as gender, age, and educational attainment across different cities. This will provide empirical evidence and decision-making support for more targeted population policies and resource allocation in the next stage of regional coordinated development.

Within this context, this study situated itself within the policy framework of the Beijing–Tianjin–Hebei coordinated development strategy. By leveraging official microdata from the 2015 1% National Population Sample Survey and the 2020 Seventh National Population Census conducted by China’s National Bureau of Statistics, we employed integrated quantitative methodologies to systematically analyze the impacts of internal population migration on the gender composition, youth population share, and average educational attainment across 13 BTH cities during 2010–2015 and 2015–2020. The analysis was contextualized through the cities’ socioeconomic development profiles to generate a multidimensional assessment. Building on these findings, we critically evaluated the implementation efficacy of regional policy objectives under the coordinated development strategy while identifying the prevailing demographic risks. This dual analytical framework aimed to contribute theoretically grounded insights and empirically robust evidence for advancing high-quality integration within the BTH region.

2. Literature Review

The current research on internal migration in the BTH region is primarily concerned with demographic economics, spatial economics, and regional development theory. Within the traditional economic framework, migration is typically conceptualized as the outcome

of individual or family decision-making in a geographic space, driven by factors such as economic opportunities, quality of life, and the costs associated with migration [25].

Beijing has completed its industrial transformation, with the economy now centered on technology research and high-end manufacturing. Those high-quality economic resources attract a considerable population, thereby rendering population dispersal a challenging endeavor. Nevertheless, the implementation of policies designed to eliminate low-end industries and evacuate the population may result in a dearth of labor in local service sectors, thereby exerting adverse effects on economic growth [26,27]. Tianjin benefits from its high-end education resources and port location conditions. Before the industrial structure reform plan, it experienced very active migration. However, in recent years, in comparison to other first-tier cities in southern China, the appeal of industrial and investment policies has been relatively weak, resulting in a reduction in the number of high-end enterprises, insufficient development of the tertiary industry, and a weakening of population agglomeration effects [28,29].

The theory of regional development places greater emphasis on the core–periphery structure that is often observed in metropolitan regions [30]. In the BTH region, Beijing and Tianjin occupy the core position, exhibiting significant economic, infrastructural, and social policy development that outpaces other cities in Hebei Province [31]. This disparity is particularly evident because certain cities in Hebei Province are undergoing rapid urbanization and critical phases of industrial transformation. Researchers have found that overcoming the “Jing-Jin” dual-core cities’ substantial siphoning effect on the population is exceedingly challenging, leaving many peripheral cities in Hebei still grappling with significant population outflows [32,33]. From 2010 to 2020, only four cities in Hebei (Shijiazhuang, Tangshan, Langfang, and Qinhuangdao) experienced net population inflows, while Handan, Baoding, and Xingtai exhibited a sustained decline in their resident populations [34].

As the research perspectives have shifted from a macro-level focus on population size to the dimension of population quality, scholars have begun to introduce more sophisticated theoretical tools to explain the mechanisms of regional population dynamics. Intensifying socioeconomic stratification now reveals that migration flows are not merely economically motivated, but that they reflect systemic disparities in migration opportunities and trajectories across social strata [35,36]. Meanwhile, regional population equilibrium theory posits that, while migration facilitates interregional resource reallocation, a self-regulating equilibrium remains constrained by institutional barriers, housing market distortions, and localized policy regimes [37,38]. Furthermore, the granular interaction thinking theory (GITT) conceptualizes macro-level phenomena such as population migration as the emergent outcomes of multidimensional interactions among micro-level social networks, economic incentives, and institutional configurations. This complex interplay critically shapes structural evolution, offering a novel explanatory paradigm for decoding the deeper institutional logics underlying internal migration patterns [39].

From the perspective of data and methodology, many previous studies have employed census data and statistical yearbooks, combined with population growth equations and survival ratio methods or census survival ratios, to conduct spatial analyses of changes in the resident population and to depict population mobility between regions or cities at a macro level [40–42]. Other studies have constructed migration flow matrices and applied Rogers’ age-specific migration rate model to conduct comparative analyses of changes in migration patterns [43,44]. Some researchers have conducted empirical analyses based on micro-level migrant surveys to identify individual characteristics and motivations of migration behavior, as well as their impacts on fertility and settlement decisions [45–47]. In recent years, with the rise in big data, high-temporal-resolution data sources such as

mobile signaling and migration trajectories have been increasingly used for migration monitoring. Combined with gravity models and social network models, these approaches have significantly enhanced the ability to capture dynamic mobility patterns [48–50].

However, these approaches also have certain limitations. For example, the net migration results derived from population growth equations may fail to fully capture the dynamic effects of bidirectional flows on population structure, and they require highly accurate data on birth and death rates, which are often subject to inconsistencies and under-reporting [51,52]. Age-specific migration rates based on migration matrices can effectively assess the migration levels of different population cohorts, but they are less capable of directly quantifying the impact of migration on demographic and social indicators such as the sex ratio, dependency ratio, and average education years [53,54]. In addition, methods based on social surveys and big data may be influenced by sampling biases and subjective perceptions, which can affect the representativeness of the data and the reliability of the results [55].

Building on the above theoretical foundations and acknowledging the limitations of the existing data and methods, this study adopted the compositional impact of the migration (CIM) method proposed by Rodríguez Vignoli and Rowe [56]. Using census microdata, they analyzed the impact of internal migration on the population structures of several Latin American cities and identified notable demographic effects, including the feminization of population structures, an extended demographic dividend period, and a decline in educational attainment. They also noted that the intensity and direction of these effects are likely to shift in response to ongoing economic and social changes in Latin American countries. Compared with traditional migration rate approaches that often focus on a single dimension, the CIM method enables the separate quantification of the contributions of in-migrants, out-migrants, and non-migrants to changes in population structure. It offers a new perspective for understanding the complexity of migration and allows for a more refined identification of how population inflows and outflows affect population structure at the city level within the BTH region, thus facilitating a phased understanding of current migration patterns.

3. Materials and Methods

The internationally accepted indicator for measuring the level of population flows is to use the “current residence” and “place of residence five years ago” to construct migration flows between regions and use this to analyze the short-term internal migration levels, which can accurately capture the precise changes in population flows [57,58]. Since 2015, China has detailed the “place of residence five years ago” down to the city-level administrative codes in the National 1% Population Sampling Survey. This is further refined to the county-level codes in the Seventh National Census, providing more comprehensive research data. In recent years, Chinese studies have also utilized spatial O-D flow matrices derived from census data to analyze internal migration patterns, providing scientific foundations for the coordinated development of urban clusters and the layout of regional economies [59–61].

Based on this, this research employed microdata from the 2015 1% Population Sample Survey and the Seventh Population Census provided by the National Bureau of Statistics' Microdata Laboratory (National 1% Population Sample Level), and processed the data using Python 3.11 (Python Software Foundation, Wilmington, DE, USA). Referring to the methodology for quantifying the impact of internal migration proposed by Rodríguez-Vignoli and Rowe (2018) [56], we adopted a cohort approach and a time-invariant assumption to construct a flow matrix based on the administrative codes of the “current residence” and “place of residence five years ago” of the population aged five and above in the survey.

We decomposed the gender-specific population, youth population, and total education years of in-migrants, out-migrants, and non-migrants across 13 cities to analyze the impact of internal migration on the gender structure, age structure, and education level. The impact on those indicators was observed using the factual value (FV) and counterfactual value (CFV) methods, with the specific formulas as follows:

Taking the sex ratio as an example, Equation (1) calculates the impact of internal migration on area i from 2015 to 2020, while Equations (2) and (3) represent the effects of in-migrants and out-migrants, respectively.

$$\begin{aligned} \text{CIM}_i &= \text{FV}_i - \text{CFV}_i = P(\text{male})_i^{2020} / P(\text{female})_i^{2020} - P(\text{male})_i^{2015} / P(\text{female})_i^{2015} \\ &= [P(\text{male})_{ii} + \sum_{j=1}^n M(\text{male})_{ji}] / [P(\text{female})_{ii} + \sum_{j=1}^n M(\text{female})_{ji}] - \\ &\quad [P(\text{male})_{ii} + \sum_{j=1}^n M(\text{male})_{ij}] / [P(\text{female})_{ii} + \sum_{j=1}^n M(\text{female})_{ij}], i \neq j \end{aligned} \quad (1)$$

$$\text{CIMI}_i = [P(\text{male})_{ii} + \sum_{j=1}^n M(\text{male})_{ji}] / [P(\text{female})_{ii} + \sum_{j=1}^n M(\text{female})_{ji}] - [P(\text{male})_{ii} / P(\text{female})_{ii}], i \neq j \quad (2)$$

$$\text{CIMO}_i = [P(\text{male})_{ii} / P(\text{female})_{ii}] - [P(\text{male})_{ii} + \sum_{j=1}^n M(\text{male})_{ij}] / [P(\text{female})_{ii} + \sum_{j=1}^n M(\text{female})_{ij}], i \neq j \quad (3)$$

In Equation (1), the factual sex ratio value FV_i for 2020 is calculated as the ratio of the number of males to females in city i in 2020. The counterfactual sex ratio value CFV_i for 2015 is calculated as the ratio of the number of males to females in city i at the “place of residence five years ago”. The year 2015 represents the counterfactual value CFV_i under the assumption that no internal migration occurred between 2015 and 2020.

Assuming that the sex ratio does not change over time, the difference between the factual value FV_i and the counterfactual value CFV_i represents the decomposed CIM (compositional impact of migration) on location i . The ratio of CIM_i to the counterfactual value CFV_i represents the percentage change in internal migration over the five-year period, denoted as $\text{CIM}_i\%$. Additionally, the population in 2020 can be decomposed into the non-migrants P_{ii} and the in-migrants M_{ji} , while the population in 2015 can be decomposed into the non-migrants P_{ii} and the out-migrants M_{ij} . By comparing the observed sex ratio with the sex ratio of non-migrants, Equation (2) allows us to determine the impact of in-migrants on the sex ratio of location i , denoted as CIMI_i , and Equation (3) allows us to determine the impact of out-migrants on the sex ratio of location i , denoted as CIMO_i . It is worth noting that CFV_i posits that the projected sex ratio outcomes under the scenario of no migration do not aim to reconstruct the actual reality but rather serve as a counterfactual benchmark for identifying actual changes. This approach enables the disentangling of contributions from in-migration, out-migration, and non-migrant populations. Since this method utilizes current data and retrospective data, it avoids including deaths and emigration during the survey period. However, it still cannot separate individuals who have returned or moved repeatedly within the five-year period [62,63].

Regarding indicator selection, we contend that the sex ratio, as a fundamental measure of population gender structure, can serve to reflect gender-specific differences in migration patterns [64]. The population age structure represents a pivotal demographic variable, offering insights into population growth types, social dependency ratios, and balanced population development [65,66]. The average years of education is a principal indicator for evaluating the cultural quality of the population, and its large sample mean can probabilistically reflect the overall level of human capital in a region. Internationally, the average years of education for populations aged 15 or 25 and above is a commonly used measure of the degree of educational modernization [67,68].

This study utilized the CIM method to analyze the sex ratio, the proportion of individuals aged 15–24 in the labor force, and the educational attainment of individuals aged 25 and above across 13 regions in the BTH urban agglomeration for the periods of

2010–2015 and 2015–2020. The data for the period of 2010–2015 were derived from the 1% Population Sample Survey of 2015, while the data for the period of 2015–2020 were derived from the seventh national census microdata. Both datasets are statistically significant for the examination of population characteristics at the city level.

Changes in gender structure of migration: During the 2010–2015 period, internal migration primarily contributed to an increase in the sex ratio. Only five cities—Zhangjiakou, Qinhuangdao, Cangzhou, Shijiazhuang, and Hengshui—had CIM values less than zero, indicating a marginal role in reducing the sex ratio. Moreover, the changes in CIM% were minor and mainly driven by CIMI, suggesting that the inflow of female migrants in these cities had only a limited effect on lowering the sex ratio. In contrast, cities such as Tianjin, Langfang, Beijing, Tangshan, Baoding, and Handan exhibited significantly positive CIM values, with high contributions from CIMI, reflecting a male-dominated migration pattern typical of China’s traditional industrial economic period.

4. Results

4.1. CIM Results

Based on the results in Table 1, the comparison between the periods of 2010–2015 and 2015–2020 revealed several detailed findings:

Table 1. Impact of internal migration on Beijing–Tianjin–Hebei cities.

Variables	2010–2015						2015–2020				
	City	CIM	FV	CIM%	CIMI	CIMO	CIM	FV	CIM%	CIMI	CIMO
Sex Ratio	Zhangjiakou	−0.242	105.794	−0.0023	−0.276	0.034	−1.062	93.39	−0.0112	0.014	−1.077
	Chengde	0.189	100.764	0.0019	0.104	0.085	0.806	98.744	0.0082	1.227	−0.421
	Qinhuangdao	−1.87	99.267	−0.0185	−1.873	0.003	0.956	101.289	0.0095	0.589	0.367
	Tangshan	1.694	101.74	0.0169	1.41	0.284	−0.028	103.154	−0.0003	0.454	−0.481
	Beijing	0.745	102.657	0.0073	1.667	−0.922	−0.201	105.681	−0.0019	1.331	−1.532
	Tianjin	9.612	113.372	0.0926	9.832	−0.22	1.338	105.733	0.0128	2.403	−1.065
	Langfang	2.868	107.713	0.0274	2.573	0.295	0.265	105.583	0.0025	−0.447	0.713
	Baoding	1.938	102.268	0.0193	1.228	0.71	−0.509	99.034	−0.0051	−0.07	−0.439
	Cangzhou	−0.289	104.513	−0.0028	−0.307	0.018	1.184	108.178	0.0111	1.588	−0.404
	Shijiazhuang	−0.218	99.009	−0.0022	−0.042	−0.177	−1.51	99.426	−0.015	−0.734	−0.776
	Hengshui	−0.074	98.15	−0.0007	−0.135	0.061	−1.763	96.071	−0.018	−0.37	−1.393
	Xingtai	0.863	104.333	0.0083	0.573	0.29	−0.798	99.917	−0.0079	0.843	−1.641
	Handan	1.685	100.238	0.0171	1.097	0.588	−1.127	100.983	−0.011	0.633	−1.76
Youth Population Proportion	City	CIM	FV	CIM%	CIMI	CIMO	CIM	FV	CIM%	CIMI	CIMO
	Zhangjiakou	−0.004	0.078	−0.0512	−0.002	−0.002	−0.014	0.079	−0.1491	0.001	−0.015
	Chengde	0.001	0.09	0.0146	0.001	0	−0.011	0.091	−0.1092	0.003	−0.014
	Qinhuangdao	0.001	0.082	0.0161	0.002	−0.001	−0.004	0.087	−0.0397	0.01	−0.014
	Tangshan	−0.005	0.093	−0.0518	−0.005	−0.001	−0.006	0.087	−0.0594	0.005	−0.01
	Beijing	0.018	0.1	0.2236	0.02	−0.002	0.023	0.091	0.3456	0.025	−0.002
	Tianjin	0.026	0.131	0.2486	0.027	−0.001	0.009	0.104	0.0939	0.016	−0.007
	Langfang	−0.003	0.102	−0.0306	−0.002	−0.001	−0.012	0.095	−0.1093	0.002	−0.013
	Baoding	−0.005	0.091	−0.0513	−0.004	−0.001	−0.013	0.091	−0.121	0.002	−0.015
	Cangzhou	−0.008	0.101	−0.0737	−0.007	−0.001	−0.015	0.089	−0.1437	0	−0.015
	Shijiazhuang	−0.005	0.107	−0.0438	−0.003	−0.002	0.008	0.106	0.0829	0.017	−0.009
	Hengshui	−0.007	0.1	−0.0629	−0.006	0	0.004	0.114	0.0355	0.021	−0.017
	Xingtai	−0.009	0.103	−0.0774	−0.008	−0.001	−0.022	0.101	−0.1789	−0.006	−0.016
	Handan	−0.011	0.107	−0.0897	−0.009	−0.002	−0.017	0.115	−0.1264	0	−0.017

Table 1. Cont.

Variables	2010–2015						2015–2020				
	City	CIM	FV	CIM%	CIMI	CIMO	CIM	FV	CIM%	CIMI	CIMO
Average Education Years (25+)	City	CIM	FV	CIM%	CIMI	CIMO	CIM	FV	CIM%	CIMI	CIMO
	Zhangjiakou	0.017	8.29	0.0021	0.022	−0.005	−0.05	9.303	−0.0054	0.042	−0.092
	Chengde	−0.006	8.453	−0.0007	0.013	−0.018	−0.019	9.195	−0.0021	0.041	−0.061
	Qinhuangdao	0.009	9.429	0.001	0.017	−0.008	−0.035	9.913	−0.0035	0.038	−0.073
	Tangshan	0.017	9.123	0.0019	0.02	−0.003	−0.017	9.853	−0.0017	0.024	−0.041
	Beijing	−0.046	11.56	−0.004	−0.038	−0.008	−0.057	12.62	−0.0045	−0.024	−0.033
	Tianjin	−0.096	10.399	−0.0091	−0.085	−0.011	−0.032	11.063	−0.0029	0.036	−0.068
	Langfang	0.045	8.864	0.0051	0.051	−0.006	0.058	9.86	0.0059	0.12	−0.062
	Baoding	0.014	8.566	0.0016	0.026	−0.013	−0.047	9.232	−0.005	0.026	−0.073
	Cangzhou	0.017	8.605	0.002	0.024	−0.008	−0.026	9.171	−0.0028	0.013	−0.039
	Shijiazhuang	0.01	9.587	0.001	0.025	−0.016	−0.023	10.34	−0.0022	0.044	−0.067
	Hengshui	0.012	8.738	0.0014	0.018	−0.006	−0.041	9.289	−0.0044	0.022	−0.063
	Xingtai	−0.013	8.419	−0.0015	0.014	−0.027	−0.026	9.07	−0.0028	0.016	−0.042
	Handan	−0.013	8.682	−0.0015	0.004	−0.016	−0.05	9.278	−0.0053	0.006	−0.055

Data source: Microdata Laboratory of the National Bureau of Statistics. Note: Due to the adjustment of administrative division codes, the data for Shijiazhuang City in the above table do not include Xinji City, and the data for Baoding City do not include Dingzhou City. The sex ratio is interpreted as the number of males per 100 females.

However, during the period from 2015 to 2020, this trend shifted significantly. Internal migration primarily contributed to a decrease in the sex ratio, with CIMO being the main component driving the reduction. This suggests a higher proportion of male out-migration during this stage, which played a balancing role in the sex ratio. In cities such as Tianjin, Tangshan, and Handan—where there had previously been large inflows of male migrants—the narrowing of CIMI indicates a decline in the absolute dominance of male inflows in traditional industrial cities. Meanwhile, in cities like Shijiazhuang and Langfang, which experienced new development, the negative values of CIMI reflect an increasing contribution from female in-migration. These changes suggest that as the BTH regional development strategy advanced, the previously male-dominated migration pattern began to weaken. Improved socioeconomic conditions and more diverse employment opportunities have enhanced women’s participation in migration, and this narrowing gender gap has played an important role in balancing the sex ratio.

Concentrated flow amid declining share of youth population: Between 2010 and 2015, most cities exhibited negative but relatively small CIM values, with the actual share of youth population ranging from 0.07 to 0.13. Beijing and Tianjin maintained high CIMI values, sustained by their strong attractiveness to young migrants. In contrast, other cities experienced weakening effects due to both insufficient young in-migration and substantial out-migration, as indicated by negative values of both CIMI and CIMO.

From 2015 to 2020, CIM values became more differentiated across cities, while the actual share of the youth population declined slightly (ranging from 0.07 to 0.115), reflecting the impact of migration-led increases in the youth population. Beijing continued to maintain a high CIMI value; although Tianjin’s value declined, cities like Shijiazhuang and Hengshui also expanded their advantage through youth in-migration. Xingtai and Handan experienced significant youth out-migration (negative CIMO) but still maintained relatively high local shares of the youth population. Cities such as Chengde, Cangzhou, and Langfang saw declining youth shares due to limited youth stock and out-migration dominance. Zhangjiakou, with its long-standing shortage of youth population and weak attractiveness, showed negative CIM values in both periods, becoming a demographic “lowland” within the region. Overall, the BTH region witnessed both a general decline in the share of the youth population and an increasing spatial polarization of youth mo-

bility. Core cities sustained their competitiveness through high levels of inflow, while most peripheral areas faced the risk of human capital shrinkage due to intensified out-migration or insufficient pull factors. This has further deepened the imbalance in the regional distribution of youth resources.

Rising educational attainment and human capital outflow: Between 2010 and 2015, the impact of internal migration primarily contributed to an increase in the average years of education among the population aged 25, as reflected by positive CIM values. Langfang benefited from the spillover effects of Beijing and Tianjin, with a high CIMI value indicating that inflows of well-educated migrants significantly raised local educational attainment. Cities such as Tangshan and Qinhuangdao had low CIMO values, suggesting limited out-migration of highly educated individuals, thereby amplifying the positive effect of educational inflows. However, in Beijing and Tianjin, CIM values were negative, mainly driven by CIMI, implying that the inflow of migrants with lower educational levels weakened average educational attainment.

During the 2015–2020 period, internal migration tended to reduce average years of education (CIM values turned negative). In Beijing, the dominant factor shifted to the accelerated outflow of highly educated individuals (a more negative CIMO), which hampered human capital accumulation. Tianjin and Shijiazhuang, with both high positive CIMI and high negative CIMO values, reflected increased mobility among well-educated individuals, yet with growing net losses. In cities such as Zhangjiakou, Handan, Baoding, and Xingtai, the severe outflow of highly educated people was not compensated by adequate inflows, resulting in an expanding human capital deficit. These patterns indicate that, although overall educational attainment improved across the BTH region due to social development, the substantial out-migration of well-educated individuals from less-developed areas poses serious challenges to the average level and quality of human capital. This trend may have long-term adverse implications for the economic and social development of these regions.

4.2. Analysis of Population Dynamics

Based on the impact of internal migration and the existing literature, we divided the thirteen cities into five regions for the analysis (Figure 2).

1. Core Area—Beijing

As the center of the BTH urban agglomeration and a pivotal growth center of China, Beijing has leveraged its advanced urbanization and a highly developed tertiary sector to attract a substantial young population. Due to internal migration, the proportion of youth increased by 22.36% in the first period and 34.56% in the second, reflecting a polarization trend. However, high living costs, labor market segmentation, and population decentralization policies have weakened the stability of the young population's residency (with the proportion of non-migrant youth ranging from 7.9% to 8.9%; see Appendix A). Consequently, Beijing exhibits a “large inflow and large outflow” migration pattern.

As projected by relevant authorities, China's current trends of significantly increasing life expectancy and declining fertility rates will lead to a contraction in the working-age population in the future [69–71]. If this migration pattern persists, it may prove to be an obstacle to the formation of a stable and sustainable population structure. Additionally, the impact mechanism of internal migration on Beijing's average years of education has changed. The CIM values were negative in both periods. However, in contrast to the preceding period, during which the influx of individuals with limited education was the primary driver of the decline, the current period has witnessed a notable shift towards a significant outflow of highly educated individuals, which has emerged as the predominant factor contributing to the reduction.

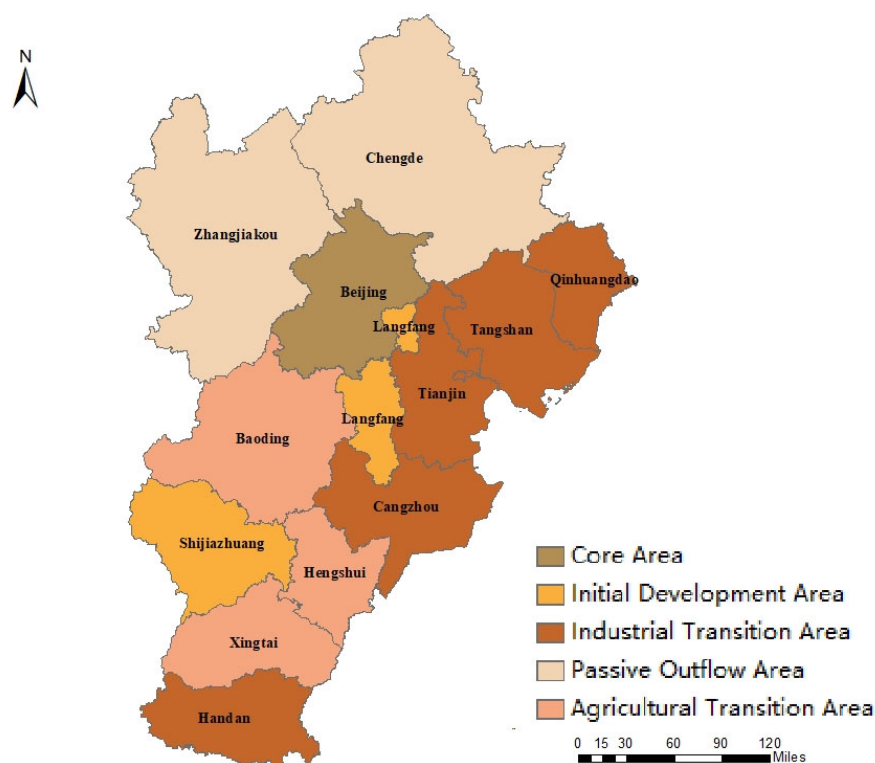


Figure 2. Internal migration types in the BTH region.

As Beijing is in the early stage of “reducing non-capital functions”, it needs to control population growth through measures such as limiting low-end industries and strictly controlling the expansion of new construction land. This is coupled with efforts to disperse and optimize the local population while encouraging migration to the peripheral areas of the BTH region. Therefore, the current migration pattern, characterized by a large influx and outflow of young and highly educated individuals, aligns with the ongoing developmental trends. However, excessive contraction may weaken the consumption market and the service sector supply. Additionally, due to the relatively underdeveloped levels of surrounding cities, the insufficient return flow of Beijing’s out-migrants has led to industrial hollowing. Thus, it is recommended to offer tax reductions, fee cuts, and social security incentives to high-quality services in elderly care, child care, domestic services, and other livelihood sectors to boost the confidence of the labor force in staying. Moreover, the surrounding cities could establish a cross-city housing, medical, and elderly care benefits recognition system to reduce the cost-of-living adjustments for returning migrants.

2. Initial Development Area—Langfang and Shijiazhuang

The educational level of the local population in Langfang is relatively low. However, as the nearest area to Beijing benefiting from its spillover effects, Langfang has attracted a significant number of highly educated individuals, thereby raising the average education years (25+) by 0.045 years and 0.058 years in the two periods, respectively. Notwithstanding these gains, Langfang has been labeled as a “dormitory” for Beijing, highlighting the mismatch between the local population and the industrial structure, as well as the separation of working and living spaces, which undermines the effectiveness of Beijing’s population decentralization policy. Additionally, with the acceleration of urbanization, the CIMO value for sex ratio was positive in 2015–2020. This is coupled with the previously positive CIMI value for the sex ratio, indicating that, following a significant influx of males, there was a substantial outflow of females. This led to a noticeable increase in the sex ratio due to internal migration.

As the capital of Hebei Province, Shijiazhuang is the only type I big city and the economic center of central and southern Hebei. It has experienced rapid development in the tertiary sector, which has resulted in an influx of females and an outflow of males. The CIM values for the sex ratio were negative in both periods, indicating a significant decline due to internal migration. As a consequence of Beijing's population decentralization policies and Tianjin's urban transition, Shijiazhuang's competitiveness as a migration destination within the BTH urban agglomeration has increased. This is reflected in the CIM value for the proportion of youth in the population, which underwent a notable transition from negative to positive in 2015–2020, with an observed increase of 8.29%. However, due to the significant development gap, the high negative CIMO value for the average education years indicates that the outflow of highly educated individuals remains pronounced.

Relying on Beijing's population control strategy and the spillover benefits of industry relocation, Langfang and Shijiazhuang have gained temporary opportunities in areas such as population structure rejuvenation and industrial upgrading. This aligns with the BTH strategy's goal of enhancing the capabilities of key cities and building a model of balanced population movement within the urban cluster. However, these cities are still constrained by the "siphoning effect" of Beijing and Tianjin. The outflow of highly educated labor may lead to an insufficient regional innovation capacity and industrial upgrading momentum, increasing the risk of future "low-end lock-in". It is recommended to shift the development approach from passively absorbing an outdated production capacity to actively creating economic growth points by leveraging local advantages. The cities should focus on sectors such as the military industry, pharmaceuticals, and telecommunications technology; develop local flagship companies and innovative industry chains; and implement preferential policies for university–business integration to mitigate the outflow of high-end talent and strengthen internal economic circulation.

3. Industrial Transition Area—Tianjin, Tangshan, Qinhuangdao, Cangzhou, and Handan

In terms of the economic structure and urban development stage, Tianjin, with a strong industrial base, experienced the largest increase in its sex ratio (9.26%) and proportion of young people (24.86%) due to internal migration in 2010–2015, making it the most active city in this region. However, in 2015–2020, Tianjin entered a post-industrial urbanization stage, characterized by a shift toward service sector growth. This shift resulted in a stagnation of industrial development, which weakened its attractiveness to males and youth [72,73]. The tertiary sector's limited capacity has led to a continual outflow of highly educated individuals. Consequently, the city, once known for active internal migration, now faces development constraints. Its dual-core spatial structure has eroded, diminishing its role as a leader in internal migration. Tangshan, Qinhuangdao, Cangzhou, and Handan are also industrial cities with heavily developed industries such as steel, coal, petrochemicals, shipping, and equipment manufacturing. These cities followed a similar trend to Tianjin, initially attracting a large inflow of males and youth.

However, with the national policies aimed at eliminating outdated production capacities and pursuing reduced development, many manufacturing plants have been re-structured or shut down, altering the positions of these cities in internal migration. As a consequence of the contraction of the industrial job market, the reduction in economic vitality, the decline in population attractiveness, and the mid-stage increase in urbanization rates, the proportion of the youth population and the average number of years of education have both declined significantly as a result of internal migration.

The advantages of youth and males concentrated in these cities, caused by traditional heavy industries such as steel and petrochemicals, have significantly weakened due to the reduction in employment opportunities under the de-capacity policy, leading to the dual pressures of labor loss and increasing aging. However, with the future innovative collabo-

native networks outlined in the BTH strategy, the development of emerging industries such as smart manufacturing and green energy presents opportunities for providing technical research, digital management, and other positions for youth, highly educated individuals, and women. This can offer a chance to reshape the population structure and improve balanced development levels. Therefore, it is recommended to break away from the traditional resource-based urban development mindset and cultivate a human-centered urban ethos. By utilizing the upstream industries and favorable transportation conditions, the focus should be on building an industrial ecosystem centered around high-end equipment manufacturing. At the same time, these cities should leverage their specialized advantages to avoid scale competition and homogeneity, creating a supporting ecosystem for high-end talent cultivation, patent protection, and technology marketing, thus enhancing industrial prosperity and advancing new productive forces.

4. Passive Outflow Area—Zhangjiakou and Chengde

Zhangjiakou and Chengde have an accelerated outflow of highly educated individuals, with the previous phase of out-migration being predominantly female, while the latter phase sees a higher outflow of males than females. In terms of age structure, they remain in a state of long-term out-migration, despite a shortage of youth labor, with their attractiveness continuing to decline as the proportion of youth in the population diminishes.

This area is located in northern Hebei Province and is predominantly mountainous and plateaued with sparse populations and fragile ecosystems, making it unsuitable for industrial and manufacturing development. Consequently, it possesses a fragile economic foundation and is currently undergoing a rapid process of urbanization. The rural labor force that is being released in the short term is unable to be absorbed by the local job market. Furthermore, the siphoning effects of Beijing and Tianjin have resulted in these cities becoming significant sources of population outflow. Given the current trends of the aging population and low fertility alongside the polarization of population mobility, this passive outflow area may face more severe challenges in the future, including an aging labor force and a shortage of young people.

Compared with cities undergoing industrial transformation, Zhangjiakou and Chengde face greater challenges due to the further decline of traditional industries and their designation as part of the ecological buffer zone in the BTH region. Local industrial development is constrained by ecological protection mandates, making it difficult to undertake specialized industrial roles within the regional collaboration framework, thus weakening urban resilience. The outflow of the population has intensified the aging crisis, creating an imbalance between rising public service demands and a limited fiscal capacity, and increasing the risk of a negative “population–economy” feedback loop. However, the region’s ecological resources offer opportunities to develop green industries such as renewable energy and eco-tourism. According to Zelinsky’s theory of mobility transition, during the post-industrial period, short-term circular mobility driven by leisure and business purposes is expected to rise [74]. Therefore, promoting female-friendly employment in sectors such as elderly care and ecological tourism services may help attract local youth and returning migrants.

5. Agricultural Transition Area—Baoding, Hengshui, and Xingtai

In the southern-central region of Hebei, cities such as Baoding, Hengshui, and Xingtai have observed a decline in their sex ratio, which is attributable to the combined impact of female inflow and male outflow. Although the proportion of youth in the population remains relatively high, with a significant number of non-migrants, the short-term loss of youth is not severe. However, the significant outflow of highly educated individuals, coupled with an insufficient inflow, has resulted in a decline in population quality. This

region, which is predominantly plains, constitutes a crucial agricultural area in Hebei, characterized by a high population density and low urbanization.

The proximity of this region to Tianjin, Shijiazhuang, and Beijing has resulted in significant regional economic disparities, rendering it more susceptible to the siphoning effect on youth outflow. Nevertheless, the rural-based fertility pattern has contributed to the maintenance of a younger population structure. Furthermore, as female educational attainment and mobility increase, alongside the increasing demand in the service sector, the “feminization of migration” trend has intensified [75,76].

As key population outflow areas, the aforementioned cities may face long-term risks of a “hollowing out” of the young population and a demographic aging gap, thereby weakening the endogenous momentum for industrial transformation. However, the goal of building modern agricultural demonstration zones has created new demand for a highly skilled and modern workforce. By encouraging the return migration of youth from Beijing to engage in emerging sectors such as smart agriculture and rural e-commerce, these regions can absorb local young labor, mitigate the siphoning effect, and foster a virtuous cycle of “skills upgrading–local employment–population stability”. At the same time, by leveraging their unique ecological resources and rural lifestyle appeal, these areas can take advantage of their transportation links to align counties and townships with the elderly care, caregiving, and vacation needs of more urbanized cities and districts in the BTH region. Promoting integrated public services such as cross-regional medical care and long-term care can strengthen differentiated development and enhance the endogenous momentum for rural revitalization.

5. Discussion

5.1. Conclusions

These are our main findings: (1) Beijing’s population decentralization is evident, but the youth population stability is low, with growth relying on external inflows, necessitating adjustments in long-term population strategies [77]. (2) Langfang, a key area for Beijing’s industrial transfer, can optimize its population structure and quality through location and policy advantages. (3) Shijiazhuang attracts a significant number of females and youth but shows a notable outflow of highly educated individuals. (4) Tianjin and other industrial cities, which previously attracted youth and males through resource advantages, have seen a sharp decline in attractiveness following a capacity reduction. (5) Passive outflow areas face high risks of aging and urban shrinkage, as they fail to provide employment for females, young workers, and the highly educated, leading to continued population loss [78]. (6) Agricultural transition areas are also losing population due to the siphoning effect, but they face lower short-term risks.

This study conducts both cross-sectional comparisons among 13 cities and longitudinal analyses between the periods 2010–2015 and 2015–2020. By integrating a counterfactual assumption approach, it provides an in-depth depiction of the dynamic changes in population structure and migration patterns in the BTH region since the implementation of the coordinated development strategy. By simulating population structures in the absence of inflows and outflows, we identify differentiated migration paths of male, female, youth, and well-educated populations across various types of cities. It reveals how industrial positioning and resource endowments have contributed to divergent trajectories of population structure evolution. The above analysis not only highlights the unevenness of regional population concentration and dispersal but also offers a quantitative foundation for understanding urban governance capacity and policy adaptability under demographic change. It thereby enriches the empirical basis for formulating sustainable regional development policies.

5.2. Discussion

Internal migration leads to systematic changes in population size, structure, and quality, yet its specific impacts are rarely discussed in current research. In this research, we conducted a decomposition of microdata for the 13 cities in the Beijing–Tianjin–Hebei area from 2010 to 2015 and from 2015 to 2020. By quantifying the specific impacts on the sex ratio, proportion of youth in the population, and average education years in each city, this analysis supplements previous research.

Despite efforts to maintain rigor in data usage and methodological design, this study has several limitations. First, the spatial and temporal coverage of the underlying data constrained the precision of the analysis. Although this study integrated two sets of microdata from the National Bureau of Statistics—the 2020 Population Census and the 2015 1% National Population Sample Survey (a one-in-a-thousand national sample)—the five-year interval between these cross-sectional datasets limited the ability to capture the dynamic evolution of population changes. This was especially relevant during the period from 2015 to 2020, when rapid urbanization was underway; the absence of annual mobility characteristics may have reduced the model’s explanatory power regarding abrupt migration events.

Second, the construction method of the migration matrix entails a loss of dynamic information. Although the bidirectional matching framework between the current residence and the place of residence five years prior can effectively capture one-time interregional moves, it fails to account for multiple moves and return migration during the interval. The unobservability of such high-mobility population trajectories may introduce systematic bias in estimating the redistributive effects of the population in the decomposition model. In particular, this may have led to an underestimation of the migration impacts in areas with high concentrations of “migratory worker” populations.

Finally, changes in administrative divisions may have introduced potential disturbances in the data comparability. During the study period, some areas underwent administrative adjustments such as the upgrading of counties to districts and the reorganization of functional zones, resulting in non-random spatial mismatches between the current residence and the residence five years prior due to changes in the administrative codes. Such institutional disruptions may have caused structural biases in the migration flow matrix.

In light of this, this study suggests that future research could adopt a multi-source validation framework by integrating three major population geographic information databases—GPS trajectory data, mobile signaling data, and household registration change records. This would allow for the use of dynamic panel models to capture the spatiotemporal heterogeneity of migration trajectories. In addition, establishing a meta-database of administrative boundary changes could enhance the longitudinal comparability of spatial units.

Furthermore, the current implementation of the BTH coordinated development strategy represents a major upgrade in China’s efforts to address “big city diseases” by exploring new pathways for urban agglomeration governance. In this process, population mobility reflects not only intergenerational demographic shifts but also interregional migration dynamics. A key challenge that remains is how to adopt more refined and scientific methods to simultaneously capture both intergenerational and interregional patterns of demographic change—and how to generalize these empirical findings to inform similar policy challenges in other countries.

Lastly, in 2017, parts of Baoding city in Hebei Province were incorporated into the newly established Xiong’an New Area, which was designated to absorb some of Beijing’s institutions and population. The full effect of this population reception function has yet to materialize, as the area is still in its early stages of development. Future research is needed

to assess the extent to which Xiong'an can effectively divert population from Beijing, what demographic characteristics—such as age, education, and skills—these migrants possess, and whether their influx can significantly enhance the population quality and structure of Xiong'an. Such insights would contribute to broader knowledge on regional coordination and development.

Author Contributions: H.M.: resources, investigation, project administration, and supervision. Y.Z.: data curation, writing—original draft preparation, review, and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Science and Technology Fund “pension financial product innovation and policy design in an aging society”, grant number 72441011, and the APC was funded by Zhejiang University.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data in Table 1 and Appendix A were derived from processed sample data from the National Bureau of Statistics—Peking University Data Development Center microdata sets. The views expressed in this article are solely those of the author and do not represent the opinions of the National Bureau of Statistics—Peking University Data Development Center or the National Bureau of Statistics.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

BTH	Beijing–Tianjin–Hebei
CIM	compositional impact of migration
CIMI	compositional impact of in-migrants
CIMO	compositional impact of out-migrants
FV	factual value
CFV	counterfactual value
DIAG	non-migrant value

Appendix A

Table A1. Supplementary table on the impact of internal migration on Beijing–Tianjin–Hebei cities.

	City	Sex Ratio		Youth Population Proportion (Aged 15–24)		Average Education Years	
		CFV	DIAG	CFV	DIAG	CFV	DIAG
2010–2015	Zhangjiakou	106.04	106.07	0.082	0.08	8.27	8.27
	Chengde	100.58	100.66	0.089	0.089	8.46	8.44
	Qinhuangdao	101.14	101.14	0.081	0.08	9.42	9.41
	Tangshan	100.05	100.33	0.099	0.098	9.11	9.1
	Beijing	101.91	100.99	0.081	0.08	11.61	11.6
	Tianjin	103.76	103.54	0.105	0.104	10.49	10.48
	Langfang	104.85	105.14	0.105	0.104	8.82	8.81
	Baoding	100.33	101.04	0.096	0.094	8.55	8.54
	Cangzhou	104.8	104.82	0.109	0.107	8.59	8.58
	Shijiazhuang	99.23	99.05	0.112	0.11	9.58	9.56
	Hengshui	98.22	98.29	0.107	0.106	8.73	8.72
	Xingtai	103.47	103.76	0.111	0.111	8.43	8.41
	Handan	98.55	99.14	0.117	0.115	8.69	8.68

Table A1. Cont.

		Sex Ratio		Youth Population Proportion (Aged 15–24)		Average Education Years	
2015–2020	Zhangjiakou	94.45	93.38	0.093	0.078	9.35	9.26
	Chengde	97.94	97.52	0.103	0.089	9.21	9.15
	Qinhuangdao	100.33	100.7	0.091	0.077	9.95	9.87
	Tangshan	103.18	102.7	0.093	0.083	9.87	9.83
	Beijing	105.88	104.35	0.068	0.066	12.68	12.64
	Tianjin	104.39	103.33	0.095	0.088	11.1	11.03
	Langfang	105.32	106.03	0.106	0.093	9.8	9.74
	Baoding	99.54	99.1	0.103	0.089	9.28	9.21
	Cangzhou	106.99	106.59	0.104	0.089	9.2	9.16
	Shijiazhuang	100.94	100.16	0.098	0.089	10.36	10.3
	Hengshui	97.83	96.44	0.11	0.093	9.33	9.27
	Xingtai	100.72	99.07	0.123	0.107	9.1	9.05
	Handan	102.11	100.35	0.132	0.115	9.33	9.27

Note: CFV refers to the counterfactual value, DIAG refers to the non-migrant value $\frac{P(male)_{ii}}{P(female)_{ii}}$, and sex ratio is interpreted as the number of males per 100 females.

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