Geographic transformation of China's internal population migrations from 1995 to 2015: Insights from the migration centerline

Abstract: Internal population migration in China is one of the most dramatic in the world. To understand the geographic dynamics of the Chinese population migration, we present a revised method called the migration centerline based on the definition of the geographic mean center of the population. Using data from the population censuses and one-percent sample surveys from 1995 to 2015, this study aims to reveal the spatial dynamics and contributors to population movements in China. The main results are as follows. (1) The directions of the population migration centerlines consistently point southeast, while the in- and out-migration centers for the five-year and non-*hukou* population migrations move north, especially from 2000 to 2010. After 2010, the west-oriented movements of the in-migration centers become pronounced, and migration distances generally decline. Five-year population migration towards the north increases from 2010 to 2015, whereas the non-*hukou* populations increased in the south in 2015. (2) The main contributors to in-migration centers are the coastal provinces, whereas out-migration centers are mostly inland provinces. (3) The geographic transformation of population migration centerlines is connected to changes in China's economic and population centers, moving south, leading to stable southeast-oriented migrations. In addition, the locations of migration centerlines are consistently further south compared with those of population centers. The migration centerline provides an intuitive and straightforward means for examining the geographic transformation of China's internal population migration and can be applied to various types of human mobilities based on different definitions or multiple spatial scales.

Keywords: population migration, internal migration, population distribution, geographic transformation, migration centerline, China

1. Introduction

Population migration has been witnessed as an essential driver of population redistribution and human settlement patterns (Czaika & de Haas, 2014, Rees et al., 2017). In addition to being defined as the social or economic process, population migration is also a typically geographical process characterized by the change of people's residential locations(Newbold, 2021). To understand the geographical patterns of population migration, it is necessary to correctly present its spatial and temporal dynamics.

Thank the available data of in-migrants in the destinations or the out-migrants in the origins, indices such as in-migration rate, out-migration rate, net migration rate, total migration rate, and migration efficiency are frequently used to reflect the spatial differences of migration situations (Liu et al., 2011). In addition to the spatial distributions of migrants, the spatial interaction from the origin to the destination is an essential geographical concern for population migration. Unfortunately, the published data on bilateral migration flows were relatively sparse (Abel & Sander, 2014). One of the advancing studies on population migration was estimating and analyzing the origin-to-destination matrix of migration flux. Apart from the gravity models, the new models, including the radiation model, intervening opportunities models, and the models linking migrant flows to stock data, were applied to generate the data of bilateral migration flows(Simini et al., 2012; Abel & Cohen, 2019; Azose & Raftery, 2019). Origin-destination migration flux, migration velocity, and migration effectiveness are standard measures for the bilateral relationships between pairs of regions (Smart, 1974; Fielding, 1992; Rogers & Raymer, 1998; Bell et al., 2002).

All of the above indicators quantify migration and allow comparisons between regions based on the respective values but do not reveal geographic changes from a global or overall perspective. Global indicators can intuitively depict the changing trend of population migration patterns over time, rather than just focusing on hot destinations, distinct origins, and top migration flows of population migration. Existing global indicators, including the spatial Gini coefficient, the variable coefficient, and the

parameters of the gravity model, the spatial interaction model, and the intervening opportunities model, are able to quantify temporal variations of migration (de Jong et al., 1984; Shen, 1999; Barbosa et al., 2018). However, these global indices failed to capture the geographical details, including the location and migration directions. Besides, the existing global indices failed to figure out the main contributors to geographical changes. Therefore, reasonable global measures on population migration are becoming more critical as the data to monitor the trend of population movement, evaluate population streams and formulate the relevant policies.

In order to address the lack of geographic examination of trends of population migrations over time, this study aims to present a global measure called the migration centerline, which covers multiple geographic information. Moreover, this study selects China, whose internal migration during the past decades was one of the eye-catching human movements on the earth, to apply the method of the migration centerline. Since China's opening up and reform in 1978, the internal population migration has been among the most dramatic human movements in the world (Fan, 2008). Many existing studies have discussed the majority of China's migration streams occurring from the west to the east due to the labor surplus in the inland region and ample employment in the coastal region(Chan et al., 1999; Liu et al., 2011; Shen, 2013; Cao et al., 2018). However, most studies on population migrations during a single period have presented a similar pattern and said little about changes over time. The recent data on interprovincial population migration flow from 2010 to 2015 shows a similar phenomenon (Qi et al., 2017). The migration centerline can be helpful to detect the geographic transformation of internal population migration in China.

Section 2 offers a review of Chinese internal migration. Section 3 presents the methodology, including an interpretation of the migration centerline and the data sources used in this study. Section 4 provides the research results of the geographic transformation of the population migrations in China. Sections 5 and 6 present the discussion and conclusion, respectively. This study focuses on data from 1995, which marks the start of China's rapid urbanization, to 2015, when the most recent China one-percent National Population Sample Survey was conducted. The study area includes 31

provincial units in Mainland China, comprising 22 provinces, four municipalities, and five autonomous regions. For simplicity, we use "provinces" to describe the 31 provincial units in the remainder of this article.

2. Internal population migration in China

Unlike most countries, population migration in China is characterized by the *hukou* system, which is the nation's household registration institution (Mallee, 1995; Chan & Zhang, 1999; Cai, 2011). *Hukou* is a kind of permit that allows the migrants to enjoy the social welfare as the local citizens. In other words, a migrant who lacks the hukou in the destination cannot be an honest citizen like those residents who possess the *hukou.* Most migrant workers are called the "floating population" because they do not possess a *hukou*-registered certificate for their destinations and cannot enjoy the complete public services available to local inhabitants (Goodkind & West, 2002; Zhu, 2007).

Before the opening up and reform in 1978, population migration in China is relatively inactive due to the strict *hukou* transfer limitations. The relaxation of *hukou*-based movement restrictions in the late 1990s enlarged the internal population migration streams (Bell et al., 2015). According to the national seventh population census bulletin, at the end of 2020, the floating population consists of 376 million people, comprising 26.62% of the total population and a considerable part of the Chinese population. In addition to their scale, the geographical landscape of population migration is also notable. Surplus rural laborers leave their hometowns for cities, boosting China's urbanization and population redistribution processes (Chan, 2012a). Counties in western, northeastern, and central regions are the main origins of sending migrants, whereas megacities in the eastern region are the popular destinations of migrants (Liu et al., 2011). In addition, social issues, including increasing public service pressures in urban areas, left-behind children or seniors in rural areas, and population shrinkage in some cities, have garnered considerable attention (Chang et al., 2011; Wang et al., 2015).

Numerous studies have tracked geographic changes in population migrations in

China. Based on data from the population censuses and mid-census one percent surveys, the spatial distributions of migrants at provincial-, prefectural-, and county-level scales are typically employed to describe China's internal migrations. Most studies focus on in-migration patterns rather than out-migration patterns because in-migrant data from statistic tabulations are accessible (He & Pooler, 2002; Fan, 2005; Li et al., 2014; Shen, 2013; Wu et al., 2018). Existing studies are also conducted from origin–destination interactions due to access to population migration matrices at the provincial level. Non-*hukou* migration is the most common type of migration, which focuses on the movement of the floating population from a *hukou*-registered location to a residential location. By contrast, *hukou* migration involves residents who change their *hukou*-registered location, presenting a different spatial pattern than non-*hukou* migration. Similar to the definition of internal migration in other countries, lifetime and five-year migrations (Bell et al., 2015; Smith et al., 2016; Qi et al., 2017; Cao et al., 2018), in which origins are birthplaces and residential locations five years previously, respectively, are also employed to illustrate the spatial dynamics of interprovincial movements in China. Using the open percent surveys of individual-level data, scholars have focused on migration patterns with demographic information, such as skilled and unskilled population migration (Chan et al., 1999; Liu & Shen, 2017; Zhou et al., 2018). Determinants such as social-economic factors and the frictions of distance are regarded as primary driving forces under the theoretical frameworks of push-pull models, gravity models, and so on (Zhang & Song, 2003; Chan, 2012a; Liang et al., 2014; Liu et al., 2015). Recently, specific factors, such as institutions, lifestyles, and amenities, have been particularly focused on (Shen, 2013; Yang et al., 2017). However, most studies said little about geographical changes of internal population migrations over time. In addition, most existing studies only identified the main in-migration destinations and out-migration origins. However, they did not focus on the main regions promoting changes in the spatial patterns of population migrations in China. The evidence from the many countries or districts has shown unstable internal migration patterns over time (Champion et al., 2017). More nuanced spatial patterns of population migration in China have evolved due to a reconstruction in economic geography and urbanization

development (Chan, 2012b).

In 2014 the Chinese government implemented the National New-type Urbanization Plan, which aimed to promote people-oriented urbanization and stimulate migrants to integrate into their habitual residence (Taylor, 2015; Bai et al., 2014; Long & Liu, 2016). The points system of the *hukou* registry, which is evaluated by education, skills, working years, and payment years of social insurance, especially in megacities, has allowed more people to settle in megacities (Wang & Liu, 2018). In addition, the government highlighted the in-situ and nearby urbanization processes of migrants to narrow regional development differences, especially in central and western China. Remarkably, the changing spatial pattern of population migration was driven by the social-economic dynamics and affected by the regulatory policies. Beyond the impacts on the spatial population patterns, a better understanding of the geography of China's internal migrations can aid efforts to address social inequality and optimizing policies, such as the New-type Urbanization plan (Shi & Liu, 2019). Is the trend of migration towards the east consistently strong and stable? Is there any new trend of the geographical changes of population migration? Who are the main contributors to the geographical transformation of population migration? In order to address these questions, a more systems-based view over an extended period of time must be created to answer these questions.

3. Methodology

3.1 Classic measurement of population mean center

The population center is a geographic point that describes the center point for a given region. It can be represented using various mathematical measures, including the mean center, media center, and geometric median. The mean center, or population centroid, can be calculated easily and is widely used to reflect the spatial dynamics of population redistribution (Kumler & Goodcild, 1992). For example, according to the computation of the US Census Bureau, the mean center of the US population moved west from 1790 to 2010, thereby indicating a relative increase in the population share of western United States. The classic equation for the population mean center is as

follows:

$$XP = \frac{\sum_{i=1}^{n}(P_i x_i)}{\sum_{i=1}^{n} P_i} \quad (1)$$

$$YP = \frac{\sum_{i=1}^{n}(P_i y_i)}{\sum_{i=1}^{n} P_i} \quad (2)$$

The terms *XP* and *YP* denote the longitude and latitude of the population mean center, respectively, x_i and y_i are the longitude and latitude of the center of province *i,* respectively. P_i represents the population of province *i,* and *n* is the number of provinces. The population mean center is determined using the population size and geographic location of each province. The calculation results are affected by the granularity of the population data or the statistical units of the population data, which is known as the modifiable area unit problem effect in spatial statistics studies. If people are distributed uniformly in a region, then the population mean center is equal to the geometric center of the region. However, population distribution is generally unbalanced, and the population mean center consistently strays from the geometric center.

3.2 Measurement of the migration centerline

Similar to the population mean center, if P_i indicates the total number of in-migrants (I_i) or the total number of out-migrants (O_i) in province *i*, then the in-migration center (*XI*, *YI*) or out-migration center (*XO*, *YO*) can be defined. Furthermore, suppose the total number of in-migrants or out-migrants occupies the same proportion of the total population in each unit. In that case, the in-migration or out-migration center is the same as the population mean center. However, due to regional development differences, some regions serve as the main out-migration origins, whereas others are popular in-migration destinations. As a result, the in-migration center is typically different from the out-migration center. Such a difference shows the geographic variation between sending-out origins and arriving-in destinations.

In this article, we introduce a novel concept called the migration centerline. The migration centerline is defined as a line that starts at the out-migration mean center and ends at the in-migration mean center. Similar to the population mean center, in-migration center, and out-migration center, the migration centerline is employed to reflect general geographic patterns. However, unlike the population mean centers, the migration centerline extends from a point to a vector, which presents geographic location details and the attributes of length and direction. The length of the migration centerline indicates the general migration distance, and its direction shows the main migration direction in the migration system.

The vector formula of the migration centerline is as follows:

$$\begin{aligned}\overrightarrow{OD} &= (XI - XO, YI - YO) \\ &= \left(\frac{\sum_{i=1}^{n}(I_i x_i)}{\sum_{i=1}^{n} I_i} - \frac{\sum_{i=1}^{n}(O_i x_i)}{\sum_{i=1}^{n} O_i}, \frac{\sum_{i=1}^{n}(I_i y_i)}{\sum_{i=1}^{n} I_i} - \frac{\sum_{i=1}^{n}(O_i y_i)}{\sum_{i=1}^{n} O_i}\right)\end{aligned} \quad (3)$$

The term $\overrightarrow{OD}$ denotes the vector of the migration centerline, with a direction from the out-migration mean center to the in-migration mean center. *XI*, *XO*, *YI,* and *YO* are the longitude of the in-migration mean center, the longitude of the out-migration mean center, the latitude of the in-migration mean center, and the latitude of the out-migration mean center, respectively. I_i and O_i indicate the total number of in-migrants and out-migrants in province *i,* respectively, and x_i and y_i are the longitude and latitude of province *i,* respectively. Accordingly, the length of the migration centerline, which is a type of vector module, can be calculated as follows:

$$\left|\overrightarrow{OD}\right| = \sqrt{\left(\frac{\sum_{i=1}^{n}(I_i x_i)}{\sum_{i=1}^{n} I_i} - \frac{\sum_{i=1}^{n}(O_i x_i)}{\sum_{i=1}^{n} O_i}\right)^2 + \left(\frac{\sum_{i=1}^{n}(I_i y_i)}{\sum_{i=1}^{n} I_i} - \frac{\sum_{i=1}^{n}(O_i y_i)}{\sum_{i=1}^{n} O_i}\right)^2} \quad (4)$$

In addition to the starting out-migration mean center and the ending in-migration mean center, any point on the migration centerline can be proven to be equal to the mean center of a proportional division of points in all the origin-to-destination migration lines, as presented in Appendix A. The findings of this derivation shown in Appendix A illustrate three quantitative relationships between the migration centerline and each migration flow from the perspective of a plane vector. First, in terms of flux,

the number of migrants is used to indicate the population weight of the migration line. Second, the direction of the migration centerline is determined by the locations of the in-migration and out-migration mean centers. Third, the length of the migration centerline reflects the general migration distance of all migration lines.

3.3 Contributions to migration centerline changes

Changes in the mean center or migration centerline show the spatial dynamics of population distribution or migration and are beneficial for understanding the geographic transformation process. To determine the locations responsible for changes in the migration centerline, we introduce the contribution degree measure for in-migration and out-migration centers. The contribution degree measure includes an east-west component and a north-south component. Using the east-west change in the in-migration center as an example, the following equation presents a decomposition procedure for calculating contribution degree measures:

$$
\begin{aligned}
XI_t - XI_0 &= \frac{\sum_{i=1}^{n}(I_{it}x_i)}{\sum_{i=1}^{n} I_{it}} - \frac{\sum_{i=1}^{n}(I_{i0}x_i)}{\sum_{i=1}^{n} I_{i0}} \\
&= \left(\frac{I_{1t}}{\sum_{i=1}^{n} I_{it}} - \frac{I_{10}}{\sum_{i=1}^{n} I_{i0}}\right)x_1 + \left(\frac{I_{2t}}{\sum_{i=1}^{n} I_{it}} - \frac{I_{20}}{\sum_{i=1}^{n} I_{i0}}\right)x_2 + \cdots \\
&\quad + \left(\frac{I_{nt}}{\sum_{i=1}^{n} I_{nt}} - \frac{I_{n0}}{\sum_{i=1}^{n} I_{n0}}\right)x_n \\
&= \sum_{i=0}^{n} \Delta S_i x_i = \Delta S_1 x_1 + \Delta S_{\ 2} x_2 + \cdots \Delta S_{\ n} x_n \\
&= \sum_{i=0}^{n} C_i = C_1 + C_2 + \cdots + C_n
\end{aligned} \tag{5}
$$

In the above equation, XI_t and XI_0 denote the longitudes of in-migration centers at terminal time t and initial time 0, I_{it} and I_{i0} represent the number of in-migrants in province i at terminal time t and initial time 0, x_i is the longitude of province i, n is the number of provinces, $\triangle S_i$ is the in-migrant's share of province i occupied by the total number of migrants and C_i is the contribution degree of province i to the longitude change which equals $\triangle S_i\ x_i$. The resulting measure provides the contribution degree

based on geographical location and the share of migrants in each province. The north-south change in the mean center can be deduced similarly by replacing x_i with y_i. By replacing the in-migration center with the out-migration center, it shows a measure for the contribution degree of each province to the out-migration center changes.

3.4 Population migration definitions in China

The censuses and mid-census one percent sample surveys provide a comprehensive set of successive population migration data for China. Similar to other nations, China has consistently used a five-year interval to measure to define population migration. Given that the census or one-percent sample survey is conducted every five years in China, the five-year migration data can reflect population migration dynamics consecutively. The five-year interval is based on questions on individuals' residential location five years before the census or survey date. Aggregations of individual's residential locations at the census or survey data and their residential location five years prior form the basis of cross-tabulations for the number of migrations between all sets of origin and destination provinces in each period. Unlike most countries, China has a particular additional definition for population migration, that is, non-*hukou* migration, owing to its *hukou* registration system. In non-*hukou* migration, the destination remains the residential location at the time of the census or survey, but the origin is the *hukou*-registered location during the same time. Although non-*hukou* migration presents an origin-destination matrix, it is akin to a migrant stock tabulation, showing the number of migrants at a specific point in time without recording the migration events. In this study, we explore the transformation of migration centerlines for five-year and non-*hukou* migrations. We aim to detect the temporal migration dynamics and specific migration issues in China.

3.5 Data sources

The tabulations of the population censuses and one-percent sample surveys provide only the interprovincial population migration matrix. Considering provincial-level administrative adjustments before 1997, our study focuses on five-year migrations

during 1995–2000, 2000–2005, 2005–2010, and 2010–2015 and non-*hukou* migrations in 2000, 2005, 2010, and 2015. The interprovincial population migration matrices are acquired from the tabulations of the 2000 census, the 2005 one-percent sample survey, the 2010 census, and the 2015 one-percent sample survey. The details of the migration data sources are listed in Appendix B. All the geographic data are from the Resource and Environment Data cloud platform of the Chinese Academy of Sciences. We use the provincial capital to represent the geolocation of each province. Moreover, we build an origin-destination spatial database for the population migration system.

4. Results

4.1 Changes in China's population migration centerline dynamics from 1995 to 2015

Fig. 1 shows China's internal population migration centerlines based on the definition of five-year population migration. The related parameters for each line are listed in Table 1. From 1995 to 2015, the population migration centerlines in different five-year periods were consistently located in Hubei, a province in central China. In addition, the directions of the population migration centerlines are all from the northwest to the southeast, which indicated a stable movement trend from the inland region to the southeast coastal region. However, the population migration centerlines from 1995 to 2015 demonstrate three forms of instability. First, the origins of the population migration centerlines or out-migrant geographic centers shift over time. Specifically, the origins moved southeast from the 1995–2000 period to the 2000–2005 period and began moving north after 2005. In general, the change in origins is driven by the increasing out-migration activity in northern China. Second, the destinations of the population migration centerlines or in-migrant geographic centers continued to evolve. The movements of the destinations were east oriented, north oriented, and northwest oriented in an orderly manner from 1995 to 2015. Distinct from the origins of the population migration centerlines, the destinations moved north and west after 2010, reflecting the populations' increasing attraction to the inland region from 2010 to 2015. Third, the length of the population migration centerlines changed owing to

variations in the origins and destinations. Lengths increased before 2005 from increasing inequalities in economic development between sending-out origins and arriving-in destinations and then began to decline.

Fig. 2 presents population migration centerlines based on the definition of non-*hukou* population migration. The parameters for these migration centerlines are listed in Table 1. Similar to the centerlines for the five-year population migrations, those from 2000 to 2010 were all situated in Hubei Province, and their direction remained from the northwest to the southeast. However, the non-hukou population migration centerlines' movements exhibited two different patterns over time in comparison to the five-year migration flows. First, the non-*hukou* lines exhibit a shift south between 2010 and 2015 after a continuous shift north in previous years, whereas the five-year population migration centerlines displayed only northward shifts throughout the entire data period, including between the 2005–2010 and 2010–2015 periods. Second, the five-year population migration centerlines the destinations moved north and west between 2005-10 and 2010-15 periods. This movement reflected a reduction in the attraction to the coastal region for migrants and a rise in in-migration activity in the inland region. For non-*hukou* population migration centerlines between 2010 and 2015, the westward movement of destinations is far less pronounced, which showed most of the non-*hukou* migrants remained in the coastal area although population attraction in inland areas was increasing after 2010.

Similar to the five-year population migration centerlines, the length of the non-*hukou* population migration centerlines decreased towards the end of the data period after initial increases between 2000 and 2005. The decline in length between 2005 and 2010, and 2010 and 2015, was a reflection of non-*hukou* migrants staying closer to their *hukou*-registered hometowns.

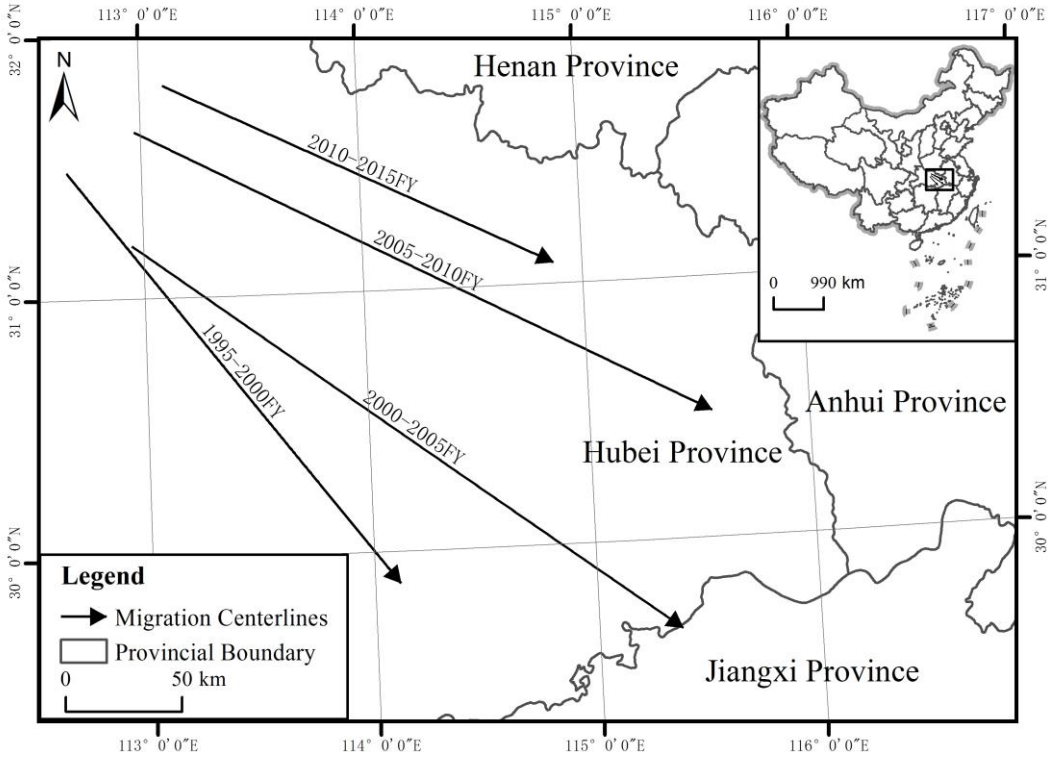


Fig. 1. Map of China's five-year population migration centerlines from 1995 to 2015

Note: FY represents five-year population migration.

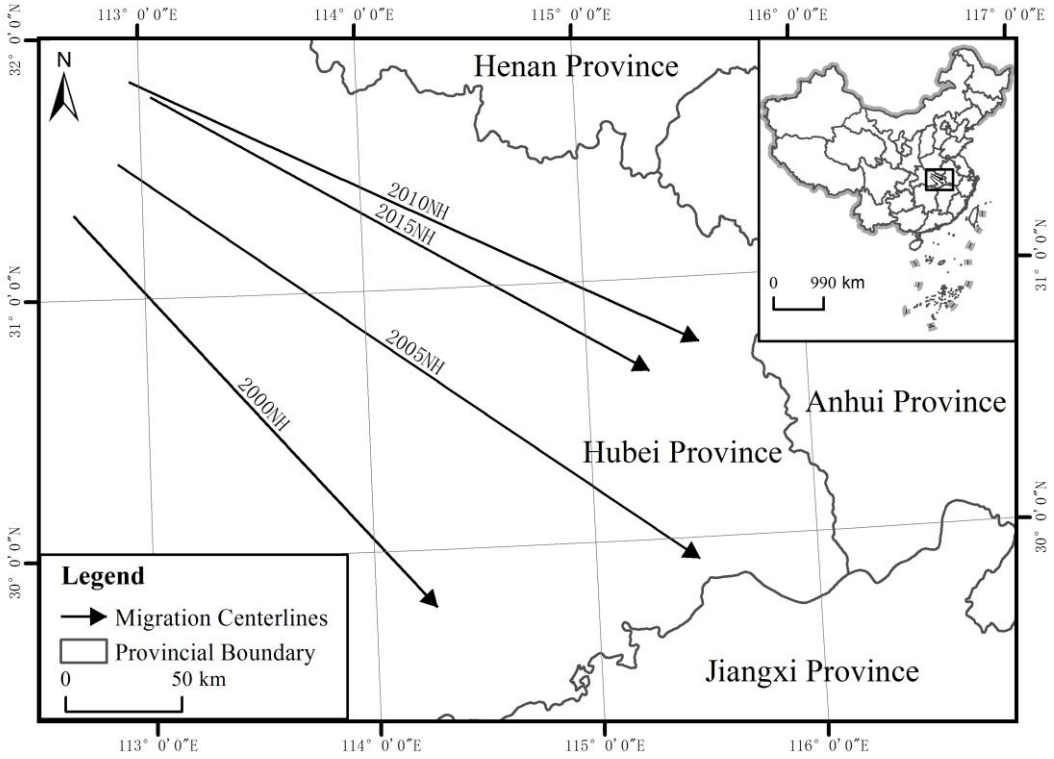


Fig. 2. Map of China's non-*hukou* population migration centerlines from 1995 to 2015

Note: NH represents non-*hukou* population migration.

Table 1

Parameters of China's internal population migration centerlines from 1995 to 2015

Migration Types	Centerline Origin	Centerline Destination	Centerline Length	Centerline Direction
Five-year migration				
1995–2000 FY	(112°39', 31°29')	(114°07', 29°53')	227.51 km	Southeast
2000–2005 FY	(112°57', 31°12')	(115°22', 29°39')	288.55 km	Southeast
2005–2010 FY	(112°58', 31°38')	(115°33', 30°29')	275.99 km	Southeast
2010–2015 FY	(113°06', 31°49')	(114°52', 31°05')	184.65 km	Southeast
Non-*hukou* migration				
2000 NH	(112°41', 31°20')	(114°16', 29°47')	229.88 km	Southeast
2005 NH	(112°54', 31°31')	(115°28', 29°55')	302.45 km	Southeast
2010 NH	(112°57', 31°50')	(115°31', 30°45')	269.46 km	Southeast
2015 NH	(113°03', 31°46')	(115°17', 30°39')	244.92 km	Southeast

Note: FY and NH represent five-year and non-*hukou* population migrations, respectively.

4.2 Contributions to changes in China's population migration centerlines from 1995 to 2015

The provincial contributions to changes in the five-year and non-*hukou* population

migration centerlines over the entire data period are mapped in Fig. 3 to Fig. 10. Fig. 3 and Fig. 4 show the contributions to the in-migration center for the five-year population migration flows by changes in the east–west and north–south components. In Fig. 5 and Fig. 6, changes in the out-migration centers for the five-year population migration flows are shown (first by the east-west components and then for the north-south components). In Fig. 7 and Fig. 8, the changes in the in-migration centers for the non-*hukou* migrant populations are provided, while in Fig. 9 and Fig. 10, the changes in the out-migration centers for the non-*hukou* migrant populations are displayed.

The in-migration center changes in the five-year population migrations from the 1995–2000 period to the 2000–2005 period, displayed in Fig. 1, show a general eastwards direction. As shown in Fig. 3 and Fig. 4, the coastal provinces such as Zhejiang, Jiangsu, Shanghai, and Fujian are notable contributors with large east-west component measures, especially in earlier periods. The notable exception is Guangdong, with large westward components in each of the periods. The north-oriented movement of the five-year population migrations during the early parts of the data period was primarily affected by increasing in-migrant percentages in Beijing, Zhejiang, Tianjin, Shanghai, and Jiangsu, as shown in Fig. 4. In the later part of the data period, Shanghai and Zhejiang joined Guangdong with large southern component values. After 2010, the coastal provinces, including Guangdong, Zhejiang, Shanghai, and Liaoning, were the main contributors that moved the in-migration centers to the west, while the inland provinces such as Shaanxi, Henan, Chongqing, Sichuan, Hubei, Anhui, Hunan, Jiangxi Guizhou, and Yunnan played an offsetting role because of the increasing shares of in-migrants in these provinces.

The out-migration centers from the five-year population migration flow, moved north during the period of 2000–2015, displayed in Fig. 1. As shown in Fig. 6, the provinces located in northern China, including Hebei, Henan, Shandong, and Shanxi, were the major contributors for the north-oriented movement of the out-migration centers from the 1995–2000 period to the 2005–2010 period. From the 2005–2010 period to the 2010–2015 period, dominant provinces, including Guangdong, Hebei,

Shanxi, Zhejiang, Beijing, and Shanghai, were distributed in northern China and southern China. Although the northward movement trends of population migration centers were similar during each period, as shown by the migration centerlines, the main contributors to the general direction had varied.

The in-migration center changes in the non-*hukou* population migrations, shown in Fig. 7, the east-oriented movement from 2000 to 2005 were mainly driven by coastal provinces, such as Zhejiang, Jiangsu, Shanghai, Beijing, Tianjin, and Fujian. The north-oriented movement from 2005 to 2010, shown in Fig. 8, was also prevailingly dominated by coastal provinces, including Beijing, Tianjin, Zhejiang, and Shanghai. From 2010 to 2015, the trajectory of the in-migration centers changed toward the southwest. Zhejiang, Shanghai, Fujian, Inner Mongolia, and Liaoning contributed to the western and southern movements.

For the out-migration centers in the non-*hukou* population migrations shown in Fig. 10, the north-oriented movement from 2000 to 2005 was led by inland provinces, such as Chongqing, Henan, Anhui, Guizhou, Heilongjiang, Hubei, and Yunnan. From 2005 to 2010, the trajectory kept moving to the north, also contributed mainly by inland provinces, including Hebei, Henan, Shandong, Gansu, Shanxi, and Yunnan. From 2010 to 2015, the out-migration centers transferred southeast. Inland provinces, including Sichuan, Anhui, Chongqing, Hubei, Henan, and Jiangxi, played a crucial role in pulling the out-migration centers to the south. In addition, coastal and inland provinces, including Guangdong, Guangxi, Shanxi, Yunnan, Zhejiang, and Shanghai, were the main contributors to the eastern movement (shown in Fig. 9).

In summary, for the five-year and non-*hukou* population migrations, the main contributors to in-migration center changes were located mainly in coastal provinces. In contrast, the out-migration center changes were primarily affected by inland provinces. Further, the attraction of in-migration to some coastal provinces decreased over the data period, whereas in-migration attraction to several inland provinces increased. Guangdong, as one of the most popular destinations for migrants, faced decreasing share of in-migrants. Fujian, Zhejiang, and Shanghai were early sources of

the increase in the shares of in-migrants in the east. However, these provinces began to lose their shares of in-migrants, especially after 2010. Tianjin and Jiangsu were the only two provinces in the coastal region that experienced an increase in the shares of in-migrants during the 2010–2015 period. Meanwhile, the out-migration shares in most coastal provinces increased, especially after 2010, pulling the out-migration centers east and north. The directions of in-migration or out-migration center change altered in some inland provinces, especially after 2010. Such geographic transformations resulted partly from the increased migration flows from the coastal region to the inland region after 2010.

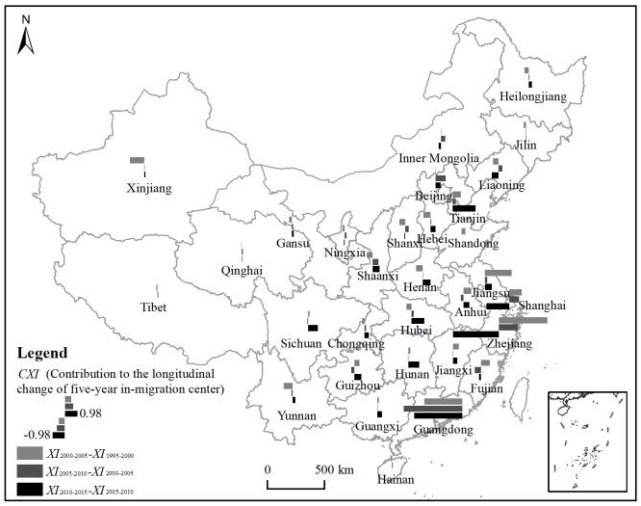


Fig. 3. Contributions to the longitudinal change of five-year in-migration centers from 1995 to 2015

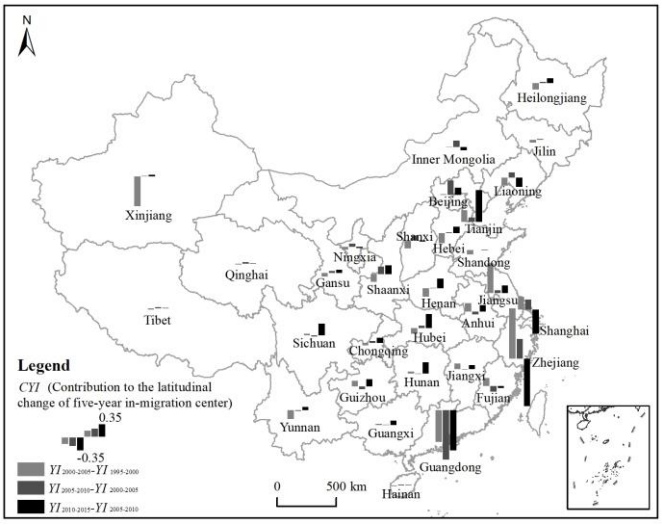
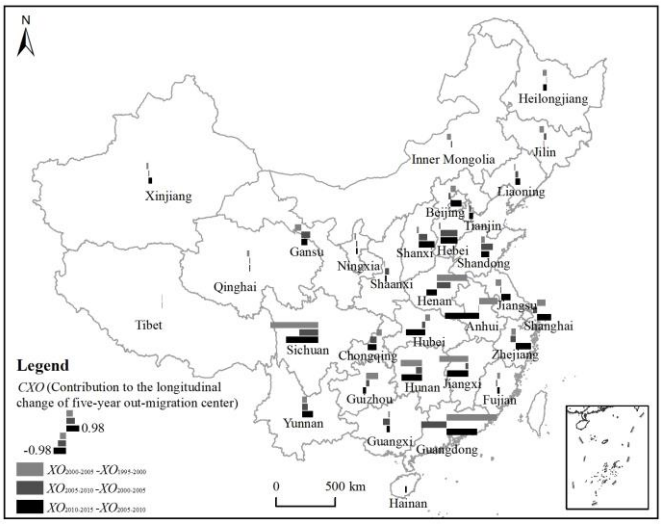
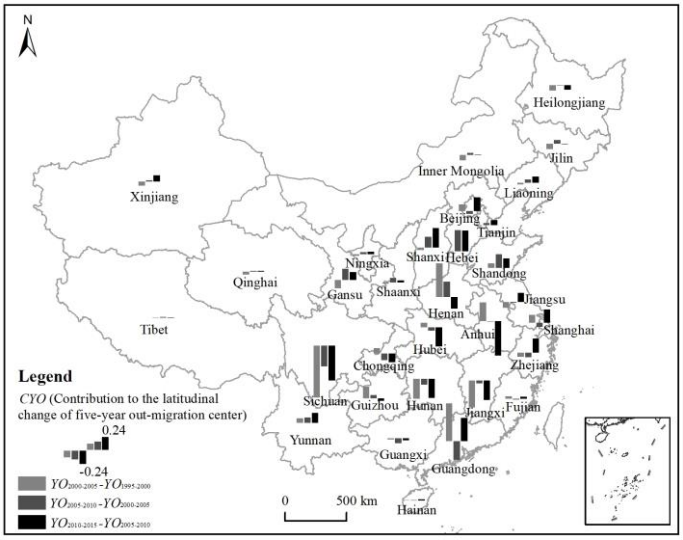


Fig. 4. Contributions to the latitudinal change of five-year in-migration centers from 1995 to 2015



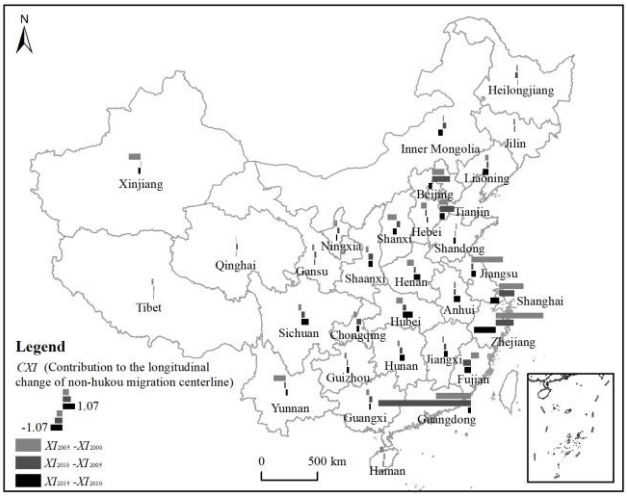
417

418 Fig. 5. Contributions to the longitudinal change of five-year out-migration centers from 1995 to 2015



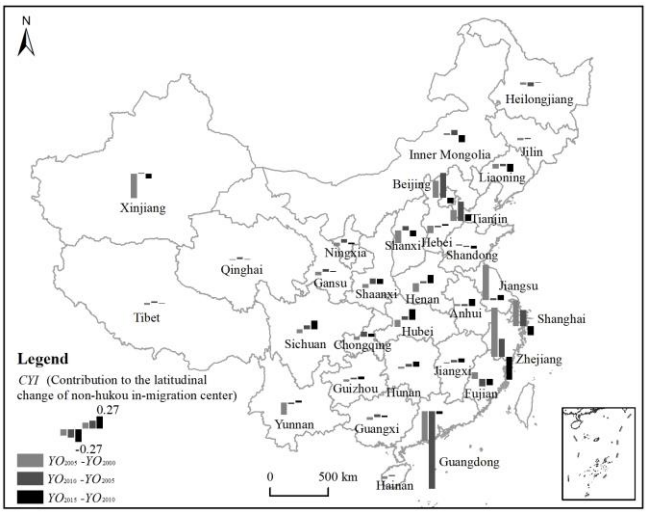
419

420 Fig. 6. Contributions to the latitudinal change of five-year out-migration centers from 1995 to 2015



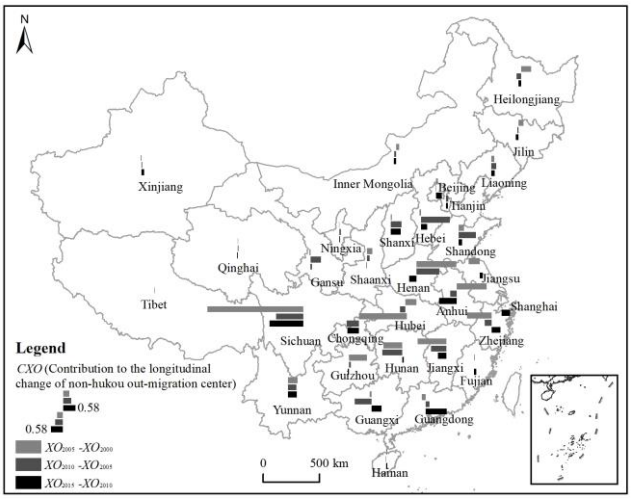
421

422 Fig. 7. Contributions to the longitudinal change of non-*hukou* in-migration centers from 1995 to 2015



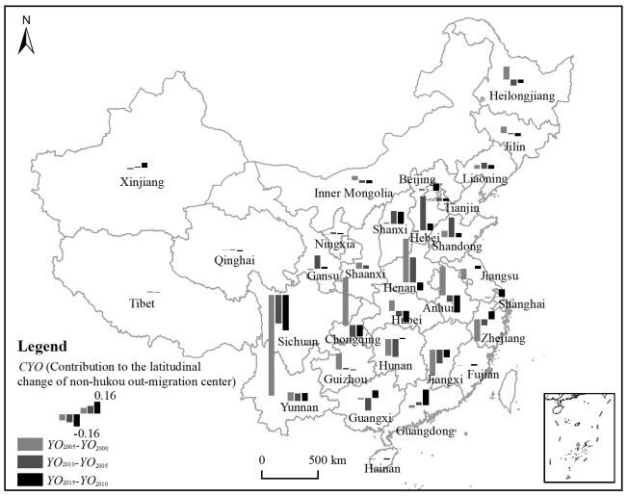
423

424 Fig. 8. Contributions to the latitudinal change of non-*hukou* in-migration centers from 1995 to 2015



425

426 Fig. 9. Contributions to the longitudinal change of non-*hukou* out-migration centers from 1995 to 2015



427

428 Fig. 10. Contributions to the latitudinal change of non-*hukou* out-migration centers from 1995 to 2015

4.3 Comparisons with population centers and economic centers

According to the push and pull theory of migration (Lee ,1966) factors operate on populations pushing and pulling potential migrants with intervening opportunities and obstacles, such as spatial distance, that lead to friction on the level of population migration (Stillwell et al., 2016). Numerous quantitative models, including the gravity model, the intervening opportunities model and the radiation model (Simini et al., 2012; Barbosa et al., 2018) have been widely applied to explain or estimate the spatial dynamics of population movements. Economic factors and transportation distance were typically selected as the key determinants of internal population migration. In China between 1995 and 2015, the length of transportation distances shortened owing to transportation network improvements, especially the expansion of the high-speed railway (Cao et al., 2013). However, the pulling effect of a destination increased and gradually became a dominating factor (Li et al., 2014). The following section examines the links between the economic centers and population migration centerlines in China.

In Table 2 and Fig. 11, the locations of the economic centers for China between 1995 and 2015 are reported and mapped, based upon calculations using provincial GDP data. Economic centers were located mainly in Henan Province or at the junction between Henan Province and Anhui Province, reflecting eastern China's considerable economic advantage over the inland region. Economic centers over the north–south axis moved mainly north from 1995 to 2010 but transferred south from 2010 to 2015.

There are several significant connections between the movements of economic centers and population migration centerlines. As discussed in the previous section, the destinations of the five-year and non-*hukou* population migration centerlines moved northwards, especially from 2000 to 2010. The five-year population migration centerlines continuously moved north after 2010 and lagged behind the south-oriented movement of economic centers. The five-year population migration centerline shortened significantly compared with that from 2000 to 2010 in line with the change in the economic centers. From 2010 to 2015, the non-*hukou* population migration centerlines moved south in sync with changes in economic centers.

458 Along the east-west axis, economic centers moved east from 1995 to 2000.
459 However, they transferred west after 2005, exhibiting similar trajectories to the
460 destinations of the five-year or non-*hukou* population migration centerlines in the east-
461 west direction. As the economy grew in central and western China, the economic gap
462 between the coastal and inland regions narrowed and prompted the population
463 migration centerlines to transfer to inland destinations.

464 The most direct effect of population migration is on the spatial redistribution of
465 the population. In Table 2 and Fig. 11, the locations of the population centers of China
466 between 1995 and 2015 are reported and mapped using the provincial residential
467 population data. All population centers during the data period were located in Henan
468 Province. Compared with economic centers, the locations of the population centers
469 were further west due to the more developed economies in the eastern. Compared with
470 the in-migration and out-migration centers in the population migration lines, the
471 locations of the population centers were further north, reflecting the intense population
472 migration activity in southern China. Although the five-year or non-*hukou* population
473 migration centerlines moved north during most periods, the centerlines pointed to the
474 southeast. This direction of the migration centerlines was a product of increased
475 migrants in the south, which is also connected to the shift of the population center
476 southwards between 1995 and 2015. Furthermore, the slide of population centers
477 eastwards from 2005 to 2010 and transfer westwards after 2010 is reflected in the west-
478 oriented movement of in-migration centers in the population migration centerlines.

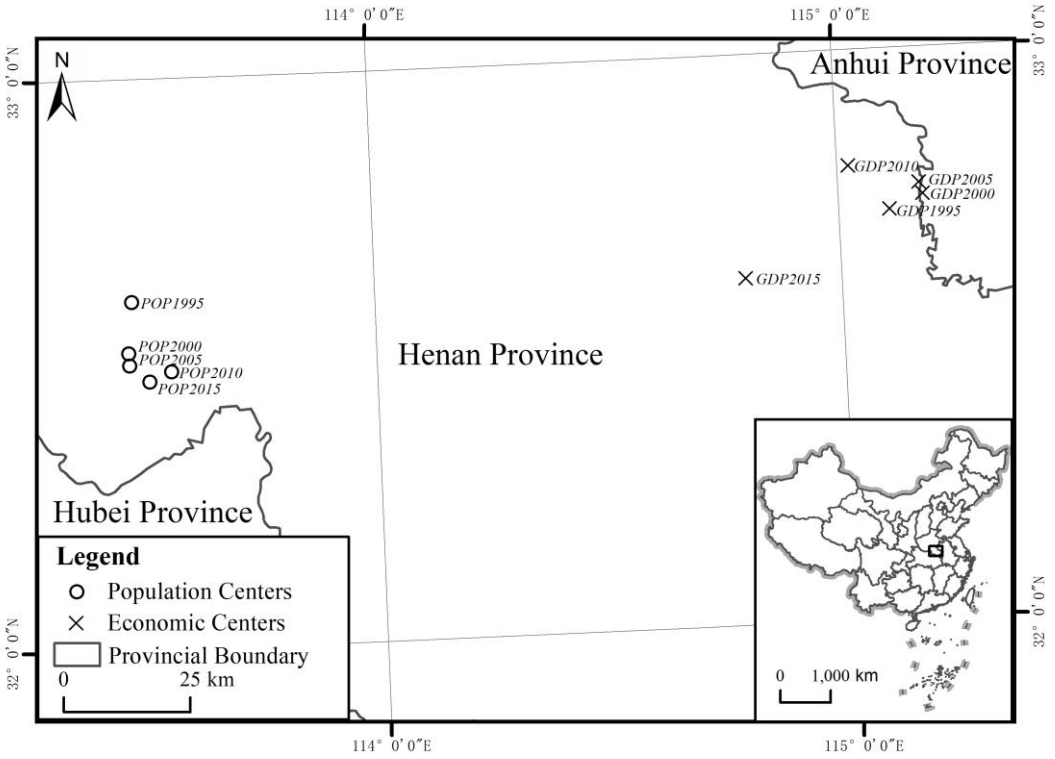


Fig. 11. Map of China's population and economic centers from 1995 to 2015

Note: POP and GDP represent the population center and economic center, respectively.

Table 2

Parameters of China's population and economic centers from 1995 to 2015

Year	Population centers	Economic centers
1995	(113°28', 32°36')	(115°06', 32°43')
2000	(113°28', 32°31')	(115°10', 32°44')
2005	(113°28', 32°29')	(115°10', 32°45')
2010	(113°33', 32°29')	(115°01', 32°47')
2015	(113°30', 32°28')	(114°47', 32°36')

5. Discussion

5.1 Data applicability of the migration centerline

By extending geographic centers from one-dimensional to two-dimensional cases, we present a novel migration centerline method. Unlike existing indices for describing the migration situation or flow of each region (Liu et al., 2011; Cao et al., 2018), the

490 migration centerline offers an intuitive way to observe the overall geographic patterns
491 of population migrations. Specifically, changes in the migration centerline are
492 extremely meaningful because they provide a number of summaries of population
493 migration dynamics, including variations in migration directions, distances, and out-
494 and in- migration centers. However, the appropriateness of census data used to calculate
495 the migration centerline should be considered carefully, especially for examining the
496 entire population migration process. We suggest two main areas of concern surrounding
497 the input data that users should be aware of when calculating migration centerlines.

498 The first concern involves whether the definition of population migration covers
499 all migrants. In the case of China, we employ five-year and non-*hukou* population
500 migrations because the related data are consecutive and attainable from the tabulations
501 of the population censuses and one-percent sample surveys. Although data sources that
502 serve as the basis for the counts of five-year or non-*hukou* have target populations that
503 cover the whole population, these data do not represent all the migrants in the country.
504 The five-year migrations cover only the "survivors" at the beginning and end of five
505 years but ignore the three other types of migrants, including those born during a five-
506 year period who migrated and survived those born during a five-year period who
507 migrated but died, and those who were alive at the start of five years and migrated but
508 died. In addition, the five-year population migrations fail to record events of repeat and
509 return migrations, which are occasionally called "transitions" in existing studies (Rees
510 et al., 2017). For example, repeat migrants move from the place *i* to place *j* to place *k*,
511 leading to two migrations (*i* to *j* and *j* to *k*) for one transition (*i* to *k*). Meanwhile, return
512 migrants move from province *i* to province *j,* then from province *j* to province *i*, leading
513 to two migrations but no transition. Non-*hukou* migration considers all age classes but
514 neglects migrants who obtain a *hukou* at a destination.

515 A second concern on the appropriateness of the input data for calculating the
516 migration centerline involves the sample. In the case of China, we consider the census
517 and sample numbers with equal uncertainty. However, the sample numbers are subject
518 to much larger random errors due to the sampling process. In China's case, only the

519 data of the non-*hukou* migrants in census years 2000 and 2010 are based on 100% of
520 the samples, whereas the data of the other migrants are based on the sampling surveys.
521 Table 3 shows the sampling fractions of the five-year and non-*hukou* migrations in
522 different years. We did not previously mention the sampling factions above because the
523 calculation of the migration centerline needs only the share of migrants rather than the
524 absolute number of migrants. Nevertheless, the sample matters for the measurement of
525 the migration centerline. The errors in the sampling process may affect the precision of
526 the in- and out-migration centers and the contributions to the migration centerline
527 changes in different provinces. For example, a small number of migrants from province
528 *i* to province *j* could be identified in the 100% sampling census but may be counted as
529 0 in the 10% or one-percent sampling surveys owing to the small number of surveying
530 samples. As a result, the share changes of the in- and out-migrants in province *i* and
531 province *j* in different years with different sampling fractions could increase or decrease.
532 As the country with the largest population in the world, a one-percent household sample
533 in China is still huge. The huge sample may narrow confidence intervals; however, it
534 cannot avoid errors. Thus, when using the migration centerline, we recommend data
535 availability and its applicability should be considered.

536 **Table 3**

537 Sampling fractions of five-year and non-*hukou* migrations in different years in China

Migration type	Census or one-percent sampling survey year	Sampling fraction (%)
Five-year migration	2000	9.5
Five-year migration	2005	1.325
Five-year migration	2010	9.55
Five-year migration	2015	1.55
Non-*hukou* migration	2000	100
Non-*hukou* migration	2005	1.325
Non-*hukou* migration	2010	100
Non-*hukou* migration	2015	1.55

538

5.2 Geographic transformation of China's internal population migrations

With regard to the stability, our findings are in line with those of existing studies (Li et al., 2014); that the general direction of the population migration is southeast-oriented. In addition, our study also shows that population migration centerlines are located consistently south of population centers. This result was driven by relatively consistently high levels of population migration activity in southern China.

With regard to the instability of spatial population dynamics, in this study, rather than focusing on the quantitative connections between population migrations and the economy (Zhang & Song, 2003; Chan, 2012a; Liang et al., 2014; Liu et al., 2015), we explored relationships from a geographic perspective. Moreover, it is easy to figure out the main divers of geographical transformation by calculating the contributions. First, as economic centers changed from south to north from 2000 to 2010, the in-migrant and out-migrant centers in the migration centerlines moved north in sync. This phenomenon corresponds with the market-oriented economy development sequence of the Peral River Delta area in Guangdong; the Yangtze River Delta area in Shanghai, Jiangsu, and Zhejiang; and the capital area in Beijing, Tianjin, and Hebei. Therefore, the earlier floating population appeared in the southern provinces. Now the population migration in north China is also active. Those less developed provinces in north China also become the distinct net out-migration area and even form some typical shirking cities. Second, the migration centerline also figured out that a distinct geographic transformation of population migration emerged after 2010. The movement of in-migration centers became highly active in the west-east direction and not merely in the north-south direction. From 2010 to 2015, in-migration centers moved significantly west, indicating an increasing in-migration attraction to inland provinces. On the one hand, the withdrawal of foreign investments in manufacturing in coastal areas, industrial upgrading in coastal areas, and industrial transfer from coastal to inland areas contributed to the increasing in-migration and return migration in inland provinces. On the other hand, China launched the "Belt and Road Initiative" in 2013 and promoted economic growth in the inland area(Liu et al., 2020). Provincial capitals in central and

western China, including Xi'an, Zhengzhou, Chongqing, Wuhan, Chengdu, and Urumqi, became the key economic hubs of the "Silk Road Economic Belt." As a result, with the increase of employment opportunities in the central and western regions, the center of population in-migration has shifted westward significantly.

From a theoretical point of view, the geographical transformation of population migration has given us some enlightenment. Recent theories show a non-linear relationship between development and levels of out-migration(De Haas, 2010; Clemens, 2014). With the development of less developed areas, for example, the central and western regions of inland China, population migration has increased. In contrast, the migration rate has changed from an increasing trend in the past to a declining trend. However, the driving mechanism of such geographical transformation is complex and diverse. For example, from the late 1960s to the early 1970s, the population of the United States migrated to the sunbelt areas, resulting in the westward shift of the population in-migration center and the population center, mainly due to the influence of new industries, climate, and other factors(Moretti, 2012). As a developing country and a world factory, China's westward shift of population in-migration center in recent years was influenced by the shift of manufacturing industry and the economic rise of its cities in the central and western regions(He et al., 2018). Tracking and examining the relationship between new factors and the contemporary geographic transformation of China's population migration is necessary to better understand migration patterns and their drivers.

From the perspective of policy implications, the migration centerline can intuitively provide policymakers with an overall description of spatial shifts in migration flows. Science, the new-type urbanization strategy, implemented in 2014, many policies have attached importance to the reform of household registration and the process of citizenization of floating population in large cities in coastal areas. Under the trend of population migration direction, the social welfare of the floating population in the new hot areas of population immigration in the central and western regions should also be concerned. Moreover, with China's population migration pattern change, the

transformation and development of emerging population loss areas should also be concerned.

5.3 Future perspectives

Our study employs the migrant centerline to investigate geographic changes in population migrations at different times. Moreover, we consider spatial differences between five-year and non-*hukou* population migrations. For example, the non-*hukou* migration centerlines show that out-migration and in-migration centers moved south. In contrast, the five-year population migration centerlines show the two centers moving north after 2010. Furthermore, the distance between in-migrant and out-migrant centers in the five-year population migrations narrows distinctly after 2010. In contrast, this distance in the non-*hukou* population migration only changes a little. Such a difference is due to the migration duration problem. For the five-year population migration measure, a movement must have occurred within five years. However, for the non-*hukou* migration measure, it is unknown when a movement occurred and is likely to be more than five years for many individuals. In future studies, the migration centerline could be helpful for comparing various types of movements, such as differences between skilled and unskilled migrants, gaps between short- and long-distance migrations, and imparities between daily intercity mobilities and permanent intercity resettlements. In addition, our methods on the contributions to migration centerline changes can be helpful to figures out the main contributors to the changes, especially under different definitions of population migrations.

Our study does not investigate the modifiable areal unit problem of the migration centerline owing to the limitations of the migration data of China. The number of migrants may be affected by contrived administrative units (Stillwell et al., 2016). For instance, Beijing is a provincial-level municipality with a small territory but a large population. In contrast, Tibet is a provincial-level autonomous region with vast lands and a large population. Consequently, the modifiable areal unit problem has a couple of notable impacts on the total number of migrants and the counts of migration flows in any origin-destination table. First, the scale of migration is directly impacted by the

626 modifiable areal unit problem. In our study, we use the exact territorial boundaries, that
627 is, those of 31 provinces of Mainland China, from a fixed point in time. However, we
628 do not explore how the migration centerline will vary if we use the migrant data on
629 smaller geographic units, including prefectural, county, and town-level boundaries.
630 Unfortunately, the tabulations of the Chinese censuses and one-percent surveys provide
631 only the total number of in-migrants based on the smaller units and lack information on
632 out-migrants and inter-unit migration flows. The second notable problem is the zoning
633 issue. The spatial pattern could be different if we have different concepts or boundaries
634 of regions. We do not test the level of differences if province boundaries are changed.
635 Existing studies explored this issue based on the IMAGE project (Stillwell et al., 2014;
636 Stillwell et al., 2016). The scholars found some variations across zone designs, which
637 did not considerably alter some migration measures. If the data in small units can be
638 accessed, then future research could potentially explore the zoning issue of the
639 migration centerline through zone designs based on the smaller units.

640 There are some obvious limitations to this study. For example, the census itself
641 has some shortcomings, including the poor timeliness of data, the impact of sampling
642 ratio, and statistical methods. However, with the application of social survey data and
643 big data, the migration centerline can be more widely used in population mobility or
644 migration. Moreover, We just made a simple comparative analysis of the population
645 and economic center. However, the mechanism of the geographic transformation of
646 population migrations is highly complex(Chen et al., 2016). In addition, other regional
647 factors, such as the natural environment, social welfare, and property prices, can affect
648 or be affected by internal population migration in China. For further research in the
649 future, these are the issues that need to be explored.

650 **6. Conclusion**

651 Using our proposed measure of a migration centerline, we explored the geographic
652 transformation of China's internal population migration from 1995 to 2015 based upon
653 both five-year and non-*hukou* population migration measures. We then discussed our
654 funding based on the calculated migration centerlines in relation to economic and

population factors. We identified the prominent provinces that were contributing to the different dynamics in the transformation of migration centers. Our main findings are as follows.

(1) The geographic patterns of China's internal population migrations changed between 1995 and 2015. As economic centers moved north, the in-migration and out-migration centers of five-year and non-*hukou* population migrations also transferred north between 2000 to 2010. However, from 2010 to 2015, the west-oriented movement of in-migration centers changed direction, in sync with the economic growth in the inland region. The general migration distance, measured by the length of the migration centerline, declined after 2010 as migrants tended to move to destinations closer to their hometowns.

(2) The most significant contributors to in-migration center changes were coastal provinces, whereas the most significant contributors to out-migration center changes were mostly inland provinces. The attraction of coastal provinces for in-migration decreased during the study period, whereas in-migration attraction to several inland provinces increased, especially after 2010. Although the similarities in the movement trends of population migration centers based on the five-year and non-*hukou* data, the main contributors to the locations of their mean migration centerlines varied.

(3) We identified a couple of constants in population migration in China between 1995 and 2015. First, the direction of population migration centerlines pointed consistently southeast, reflecting the more significant attraction to the southeast coastal region. Second, the locations of in-migration and out-migration centers were consistently further south than those of population centers, indicating that population migration was highly active in the south. The population centers continuously moved south, partly due to the stable southeast-oriented migration direction over the period.

The migration centerline allows for a simple illustration of the geographic transformation of population migration. This novel method can be extended to reflect the spatiotemporal changes of various movements, including international population migrations, refugee trajectories, and daily commutes. Thus, the migration centerline can aid the understanding of changes in human footprints around the world. In future studies,

685 we would like to explore the modifiable areal unit problem of the migration centerline
686 and improve the method to examine the causes and effects of changes in the migration
687 centerline based on related developmental factors.

688 **Appendix A. Proportional location on migration centerline**

689 We can define a proportional location on a migration center line by considering *k*,
690 a value between zero and one, where *k = 0* refers to the origin of the migration centerline,
691 and *k = 1* is the destination of the migration centerline. If we are interested in, for
692 example, the median location of the migration centerline, we derive it as:

693 $$XK = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[F_{ij}k(x_i+x_j)]}{\sum_{i=1}^{n}\sum_{j=1}^{n}F_{ij}} \quad (6)$$

694 Where x_i and x_j are the east–west latitude location of the centroids for province *i* and *j,*
695 and F_{ij} is the size of the migration flows between province *i* and *j*. We can express a
696 similar proportional location for the north-south longitude location using y_i and y_j in the
697 equation above.

698 The calculation of the point *XK* can be simplified to

700 $$XK = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[F_{ij}k(x_i+x_j)]}{\sum_{i=1}^{n}\sum_{j=1}^{n}F_{ij}}$$

701 $$= \frac{(\sum_{i=1}^{n}F_{i1}+\sum_{j=1}^{n}F_{1j})kx_1 + (\sum_{i=2}^{n}F_{i2}+\sum_{j=1}^{n}F_{2j})kx_2 + \ldots + (\sum_{i=1}^{n}F_{in}+\sum_{j=1}^{n}F_{nj})kx_n}{\sum_{i=1}^{n}\sum_{j=1}^{n}F_{ij}}$$

702 $$= \frac{(I_1+O_1)kx_1 + (I_2+O_2)kx_2 + \ldots + (I_n+O_n)kx_n}{\sum_{i=1}^{n}\sum_{j=1}^{n}F_{ij}}$$

703 $$= \frac{k(\sum_{i=1}^{n}I_ix_i + \sum_{j=1}^{n}O_jx_j)}{\sum_{i=1}^{n}I_i} = \frac{k(\sum_{i=1}^{n}I_ix_i + \sum_{j=1}^{n}O_jx_j)}{\sum_{j=1}^{n}O_j}$$

704 $$= k\left(\frac{\sum_{i=1}^{n}I_ix_i}{\sum_{i=1}^{n}I_i} + \frac{\sum_{i=1}^{n}O_jx_j}{\sum_{j=1}^{n}O_j}\right)$$

699 $$= k(XI + XO) \quad (7)$$

705 where *XI* and *XO* are the mean centers of in-migrants and out-migrants, respectively
706 based on the inflow and totals *I* and *J* for each province

707 **Appendix B. Data sources**

708 The population migration data in our study are obtained from the publicly
709 published tabulations of the National Bureau of Statistics.

The 2000 fifth census data are acquired from http://www.stats.gov.cn/tjsj/pcsj/rkpc/5rp/index.htm and the tabulation of the 2000 population census of the People's Republic of China (*in Chinese*: 中国 2000 年人口普查资料).

The 2005 1% population survey data are obtained from http://www.stats.gov.cn/tjsj/ndsj/renkou/2005/renkou.htm and the tabulation of the 2005 1% population survey of the People's Republic of China (*in Chinese*: 2005 年全国 1%人口抽样资料).

The 2010 sixth census data are available in http://www.stats.gov.cn/english/Statisticaldata/CensusData/rkpc2010/indexch.htm and from the tabulation of the 2010 population census of the People's Republic of China (*in Chinese*: 中国 2010 年人口普查资料).

The 2015 1% population survey data are obtained from the tabulation of the 2015 1% population survey of the People's Republic of China (*in Chinese*: 2015 年全国 1% 人口抽样资料).

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