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Regionalization in the Yangtze River Delta, China, from the perspective of inter-city daily mobility

Weiyang Zhang[a], Ben Derudder[b], Jianghao Wang[c] and Wei Shen[d]

ABSTRACT

Regionalization in the Yangtze River Delta, China, from the perspective of inter-city daily mobility. *Regional Studies*. This paper applies a community detection algorithm to the Yangtze River Delta's (YRD) daily inter-city mobility network to produce an interaction-based regionalization, and then explores the processes underlying this regional (re-)production by comparing it with attribute-based regionalization. The results show that political boundaries and historical patterns of socio-economic integration are strikingly visible, and the effects of overlapping physical, economic, cultural and administrative spaces on regional integration are apparent. The authors conclude that both notions of 'territory' and 'network' come together as the YRD region is spatially configured, while 'regional path dependence' also seems to be relevant for understanding its relational formation.

KEYWORDS

regional geography; regionalization; urban interaction; human movements; community detection; network analysis; Yangtze River Delta

摘要

基于城际日常流动视角的中国长江三角洲区划研究。*Regional Studies*. 本文通过将社区探测技术应用至长三角（YRD）城际日常流动网络，进行了基于城际联系的区划，并通过与基于属性的区划方案进行对比，探索此一区域的（再）形成过程。研究结果发现，政治边界和社会经济整合的历史形成显而易见，且自然、经济、文化和行政空间对区域融合起到显著的叠加作用。本研究于结论中主张，"领域"和"网络"共同作用于长三角区域的空间组织，且"区域路径依赖"也似乎适用于理解区域的关系构造。

关键词

区域地理; 区划; 城际互动; 人口移动; 社区探测; 网络分析; 长江三角洲

RÉSUMÉ

La régionalisation dans le delta du Yangtze, en Chine, du point de vue de la mobilité quotidienne interville. *Regional Studies*. Cet article applique un algorithme de détection de la structure communautaire au réseau de la mobilité quotidienne interville dans le delta du Yangtze pour élaborer une régionalisation fondée sur l'interaction, et il s'ensuit un examen des processus sous-jacents de cette (re-)construction régionale en la comparant à la régionalisation fondée sur les attributs. Les résultats laissent voir que les frontières politiques et l'évolution historique de l'intégration socioéconomique sont tout à fait évidentes, et que l'impact des zones de chevauchement physiques, économiques, culturelles et administratives sur l'intégration est plus marqué. Les auteurs concluent que les notions de 'territoire' et de 'réseau' se réunissent parce que le delta du Yangtze est configuré sur le plan spatial, alors que la notion de 'dépendance du sentier' à l'échelle régionale semble aussi aider à comprendre sa formation relationnelle.

CONTACT

[a] weiyang.zhang@ugent.be
Department of Geography, Ghent University, Ghent, Belgium.
[b] ben.derudder@ugent.be
Department of Geography, Ghent University, Ghent, Belgium.
[c] **(Corresponding author)** wangjh@lreis.ac.cn
State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Sciences & Natural Resources Research, Chinese Academy of Sciences, Beijing, China.
[d] wei.shen@lancaster.ac.uk
Confucius Institute, Lancaster University, Lancaster, UK; and EU-Asia Institute, ESSCA School of Management, Angers, France.

MOTS-CLÉS
géographie régionale; régionalisation; interaction urbaine; mobilité humaine; détection de la structure communautaire; analyse des réseaux; delta du Yangtze

ZUSAMMENFASSUNG
Regionalisierung im chinesischen Yangtze-Delta aus der Perspektive der täglichen interurbanen Mobilität. *Regional Studies*. In diesem Beitrag erzeugen wir durch Anwendung eines Gemeinschaftserkennungs-Algorithmus auf das tägliche interurbane Mobilitätsnetzwerk im Yangtze-Delta eine auf Wechselwirkungen basierende Regionalisierung und untersuchen durch einen Vergleich mit der attributbasierten Regionalisierung die dieser regionalen (Re)produktion zugrundeliegenden Prozesse. Die Ergebnisse zeugen von frappierend sichtbaren politischen Grenzen und historischen Abläufen der sozioökonomischen Integration sowie von deutlichen Auswirkungen von sich überschneidenden physischen, wirtschaftlichen, kulturellen und administrativen Räumen auf die regionale Integration. Wir ziehen den Schluss, dass sich die Begriffe des 'Gebiets' und 'Netzwerks' bei der räumlichen Konfiguration der Yangtze-Delta-Region miteinander verbinden, während die 'regionale Pfadabhängigkeit' ebenfalls für ein Verständnis ihrer relationalen Bildung relevant zu sein scheint.

SCHLÜSSELWÖRTER
Regionalgeografie; Regionalisierung; Wechselwirkungen zwischen Städten; menschliche Bewegungen; Gemeinschaftserkennung; Netzwerkanalyse; Yangtze-Delta

RESUMEN
Regionalización en el delta del río Yangtsé, China, desde la perspectiva de la movilidad interurbana diaria. *Regional Studies*. Mediante un algoritmo de detección comunitaria para la red de movilidad interurbana diaria en el delta del río Yangtsé, en este artículo producimos una regionalización basada en la interacción, y luego analizamos los procesos que subyacen en esta (re)producción regional comparándola con la regionalización basada en atributos. Los resultados muestran que las fronteras políticas y los patrones históricos de la integración socioeconómica son sorprendentemente visibles y que los efectos del solapamiento de espacios físicos, culturales y administrativos en la integración regional son evidentes. Concluimos que ambas nociones de 'territorio' y 'red' van de la mano, dado que la región en el delta del río Yangtsé está configurada espacialmente, mientras que la 'dependencia de la ruta regional' también parece ser relevante para entender su formación relacional.

PALABRAS CLAVES
geografía regional; regionalización; interacción urbana; movimientos humanos; detección comunitaria; análisis de redes; delta del río Yangtsé

JEL O18, R1, R58
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INTRODUCTION

In the literature on mega-city-regions (Hall & Pain, 2006) or their near analogues such as global city-regions (Scott, 2001) and polycentric metropolises (Kloosterman & Musterd, 2001), the development of China's mega-city-regions has attracted increasing attention (Li & Phelps, 2016; Liu, Derudder, & Wang, 2017; Liu, Derudder, & Wu, 2016; Vogel et al., 2010; Xu & Yeh, 2010; Zhang & Kloosterman, 2016). One basic characteristic of China's mega-city-regions is their considerable geographical extent. For example, the Yangtze River Delta (YRD) – an archetypal mega-city-region in China – is substantially larger than its ostensible counterparts in other parts of the world, such as the South East of England and the Dutch Randstad. According to the geographic delineation adopted in the YRD Urban Agglomeration Development Plan (YUADP), as implemented by the National Development and Reform Commission, the region covers an area of 211,700 km^2, which is comparable in size with the UK as a whole. Within such a large territorial framework, the regional diversification of physical, economic, cultural and administrative spaces becomes obvious. The YRD spans plains, basins and mountains; includes multiple economic alliances designated by multilevel governments; stretches across different cultural areas; and consists of four provincial-level political spaces. To date, relatively little attention has been paid to this regionalization within China's mega-city-regions. In this paper, we seek to address this research lacuna by examining regionalization within the YRD.

Regionalization research has long relied on attribute-based approaches, whereby homogeneous regions have been delineated based on geophysical, economic, socio-cultural or political commonalities. However, it has been recognized that such attribute-based regionalization and their absolute boundaries can be supplemented or replaced by interaction-based regionalization in which territories are deemed 'unbound' (cf. Amin, 2004). The key point

supporting this argument is that regional delineations generated through an attribute-based approach may fail to reveal how the territorial coherence of regions is (re)created: a 'region' is above all (re)produced through processes of spatially interconnected socio-economic activity. More specifically, this approach recognizes that regions should not reflect preconceived frameworks that may or may not reflect activity and flows within and across a given regional space. Rather, such frameworks are at best a heuristic device that captures a significant part of the geography of interconnected socio-economic activity (Pred, 1984; Söderbaum & Taylor, 2008). Following this rationale, this paper attempts to understand the YRD's regional organization by describing an interaction-based regionalization based on patterns of actual daily mobility and discussing how such patterns relate to possible attribute-based regionalization.

This objective is achieved in two consecutive steps. First, we 'regionalize' by analysing network formation in the YRD from the perspective of the density of inter-city interaction. The 'network turn' (cf. Ducruet & Beauguitte, 2014) in urban research has stimulated research that is useful for creating such 'interaction-based' regions. For instance, Taylor, Derudder, Hoyler, and Ni (2013) recently presented a specific regional geography of globalization based on the uncovering of regionalized location strategies of leading advanced producer service firms. In our research, we apply a community[1] detection approach to divide the YRD into sub-regions in which cities are more closely connected to one another. The information on inter-city mobility is derived from Weibo, a major Chinese online social networking and micro-blogging service. Because Weibo users can 'geo-tag' their movements, Weibo has the potential to link social practices to inter-city engagements (Zhang, Derudder, Wang, Shen, & Witlox, 2016). Second, this interaction-based regionalization is compared with physical–economic–cultural–administrative (PECA) regionalization. In this way, the link between this interaction-based regionalization and territorial regional formation can be investigated.

This paper also has a second objective. Through primarily empirical research, we seek to contribute to the conceptual debate on the coexistence of 'networks' and 'territories' in the (re)productions of regions. The debate on whether a region is 'territorially embedded' or 'relational and unbound' has been addressed from a range of social and economic–geographical perspectives (e.g., Giddens, 1984; Gilbert, 1988; Thrift, 1983). Although it has been recognized that 'territorialization' and 'networking' combine as a 'regional world' that is (re)configured (Harrison, 2013; Hudson, 2007; Jessop, Brenner, & Jones, 2008), there is relatively little empirical research that attempts to confront the approaches. Therefore, this paper can also be viewed as an empirical investigation of how the approaches interact.

The paper is structured as follows. The next section provides a general discussion of the PECA regionalization of the YRD. It is followed by a section in which we introduce our data and methods. The subsequent results section is presented in three parts: a discussion of the interaction-based regionalization, the comparison of such regionalization with PECA regionalization, and a discussion on the similarities and differences between the two. The paper concludes with an overview of its major findings, policy implications and suggestion for avenues of future research.

DIVISION OF THE YANGTZE RIVER DELTA'S REGIONAL SPACES

In this section, we present the *territorial* PECA regionalization of the YRD. Territories have long been understood as bounded and fixed spaces that have some type of intra-territorial coherence. This coherence can have geophysical, economic, socio-cultural and political characteristics. In contrast, 'network' indicates interconnected socio-economic practices, which reflects an understanding of regions as unbound, fluid and relational. Although territory and network seem to be rival ideas of spatial organization, there is increasing support for the argument that they should not be viewed as incommensurable but as interconnected and concurrent (Harrison, 2013; Jones, 2009; Macleod & Jones, 2007; Painter, 2010). As Painter (2010, p. 1090) notes, 'territory can be seen as itself a product of relational networks'. For instance, a 'cultural region' can be understood as the outcome of historical interconnections of culture-related social practices, such as language. From this standpoint, we introduce the territorial division of the YRD in line with the 'economic, cultural, environmental and political projects' proposed by Jonas and Ward (2007, p. 176): (1) hierarchical administrative divisions, (2) uneven landform patterns, (3) language-based cultural disparities and (4) emerging regional (economic) alliances (created by multiple central state-led regional plans).

In our study, the YRD is understood to include Jiangsu, Zhejiang and Anhui provinces and the municipality of Shanghai. It consists of 89 statutory cities: one municipality-level city, 40 prefecture-level cities and 48 county-level cities (Figure 1(a); for city codes used in the figures, see Appendix A in the supplemental data online).[2] The region is arguably one of China's main economic engines. Although it only occupies 3.6% of the nation's total land resources and is home to 16.6% of the population, the region generated 23.5% of the national gross domestic product (GDP), 23.9% of the national fiscal revenue, and received 41% of China's inward foreign investment in 2014.

Administrative regions

Administrative barriers may play a crucial role in regional (re-)production through regulating fixed spatial configurations and territorial assets, such as infrastructure (Zhang & Wu, 2006). Since the economic reforms started in 1978, China has adopted a series of decentralization policies that empower local states in the distribution of administrative and economic powers with the central government. The emerging 'entrepreneurial local states' (Wu, 2002) epitomize this transformation of the governance system. That is, local governments have strong incentives to shield

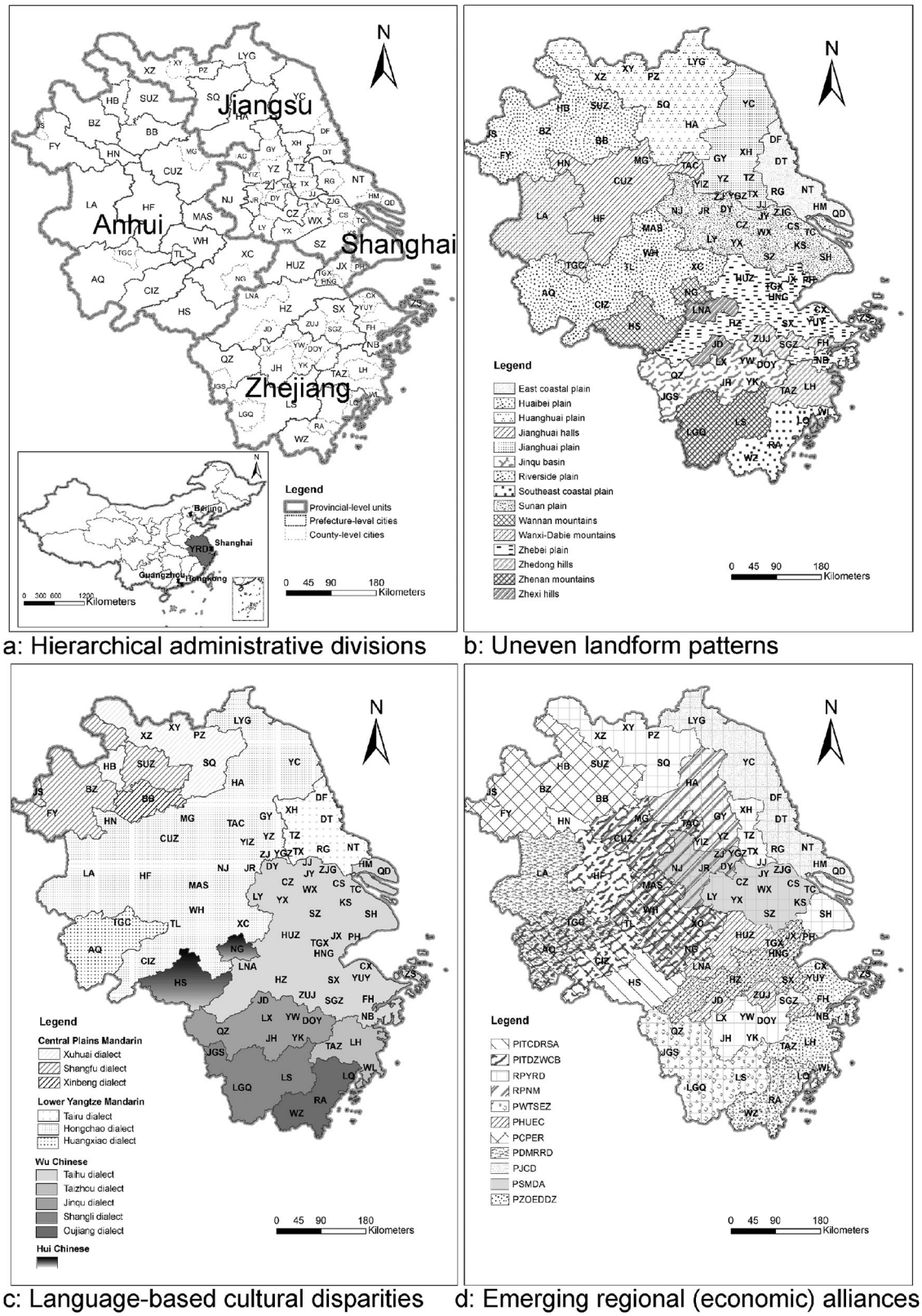

Figure 1. Attribute-based regionalizations of the Yangtze River Delta.

local firms and industries from interregional competition. At the same time, another factor contributes importantly to the territorial division of the YRD: the unique household registration system (*hukou*), which institutionally restricts migrant labourers from moving freely across different administrative borders. Taken together, the effects of the administrative borders on socio-economic interaction have persisted and are probably much stronger than in the West, where 'the effects of territorial boundaries on the flows of local and non-local forces are not absolute as the boundaries are generally porous' (Ma, 2005, p. 484). Figure 1(a) maps the administrative divisions at the provincial and prefecture scale.

Uneven landform regions

Regional identity has often been affected by physical boundaries. Prior to the Industrial Revolution, physical conditions profoundly restrained people's movements and related socio-economic activities. Thus, the geographical environment often shaped inter-city interaction. Industrialization has resulted in a substantial shift in mobility and accessibility through the rapid construction of large-scale transportation infrastructures. Additionally, the development of information technology has reduced the constraint of physical space and distance. However, physical boundaries may still act as a significant complement to social and economic interactions, particularly those that involve physical flows at a regional scale. For instance, the Northeast Zhejiang Plain Region within the YRD has been well connected with other cities within northern China through a network of rivers and canals since the Sui dynasty (581–618 CE), and this network has been considered one important reason for its contemporary prosperity (Lin, 1992). Landform patterns are adopted in this paper as a major component of the physical environment. Figure 1(b) presents a regionalization based on 15 landform regions.[3] The regionalization is based on the landform partitions in the 'major function-oriented zone planning' (a main spatial planning system in China) of Anhui and Jiangsu provinces and the self-description of Zhejiang province at its governmental website.

Language-based regions

Linguistic affinities may also consolidate socio-spatial segregations and agglomerations (Wu, Wang, & Dai, 2016) and thus could play an important role in the (re)production of regions. In the Chinese context, although Mandarin Chinese (*Putonghua*) is the official language, significantly different dialects and local languages exist, among which Cantonese is a well-known representative. These dialects were historically associated with administrative regions during imperial times. However, they have also been essential for China's contemporary socio-economic interaction. A typical example is how the distinct Oujiang dialect in Wenzhou facilitates the formation of the 'thick' local institutions of that region's business networks (Wei, Li, & Wang, 2007). Figure 1(c) maps the YRD's dialect zones to show the language-based cultural disparities, whereby four dialect zones and 12 sub-dialect zones are delineated. The original data are from the 2012 Atlas of Chinese Dialects, which documents the results of the comprehensive language survey organized by the Chinese Academy of Social Science (Xiong & Zhang, 2012). Generally, the dialect patterns within the YRD are diverse, and the Taihu dialect zone is broadly in line with the YRD's core region.

Emerging regional (economic) alliances

Another product of China's economic/administrative restructuring is the emergence of inter-city cooperation in response to interregional friction. The increasing regional (economic) alliances manifest themselves through the mushrooming regional plans, formal/informal regional cooperation and large-scale administrative annexation (Li & Wu, 2013; Ma, 2005). An obvious example is the proliferation of multiple central state-led regional plans (CSLRPs; for CSLRP codes, see Appendix A in the supplemental data online) through which the central government has reasserted its power in regional governance (Chen, Zhang, Li, & Zhang, 2014). Local governments aspire to be designated an 'urban region' to pursue their economic interests and showcase their strategic importance (Liu et al., 2016; Wu & Zhang, 2007). As a consequence, the YRD's spatial organization seems to have been restructured into a fragmented, overlapping combination of a series of regional alliances (Chen, Song, & Yang, 2013). In our research, we map the emerging urban regions designated by CSLRPs as our sample of these regional alliances within the YRD. Figure 1(d) maps the CSLRPs that cover more than one YRD city promulgated since 2010.[4] The multiple overlaps of the CSLRPs are notable. For instance, Nanjing is included in three CSLRPs, i.e., PSMDA (Plan for Sunan Modernization Demonstration Area), RPNM (Regional Plan for Nanjing Metropolitan) and RPYRD (Regional Plan for the Yangtze River Delta), which indicates its close cooperation with Southern Jiangsu, the Nanjing city-circle and the core region of the YRD (i.e., Jiangsu and Zhejiang provinces and the municipality of Shanghai), respectively.

DATA AND METHODS

Deriving human mobility information from Weibo

In this section we describe the Weibo data we use and test their validity in the context of our research. Weibo, which means 'microblog' in Chinese, can best be described as a hybrid of Twitter and Facebook. Its users are allowed to post short texts that express impressions, information and daily activity. They can also share their location through a 'geo-tagged' service. A geo-tagged post contains information on where and when the user posted the message. Thus, a user who multi-tags information in different cities has the potential to reflect his/her inter-city mobility. In a previous study (Zhang et al., 2016), the potential of Weibo data for analysing inter-city geographical patterns was verified. Here, we focus on the data required for this particular study and an approach for generating day-to-day inter-city movements from geo-tagged records.

Weibo provides a public application–programming interface (API) for application developers to search and download messages. In our study, the API was used to gather the geo-tagged records submitted within the YRD between January 2014 and November 2014. The dataset contains 53.52 million geo-tagged records, which is 6.05% of all Weibo records submitted in the same region and period. These geo-tagged records were posted by 7.03 million users, which is 32.89% of the monthly active users registered in this region[5] and 3.09% of the overall regional population. These records provide information on post content as well as spatial (geographic coordinates) and temporal information associated with the post.

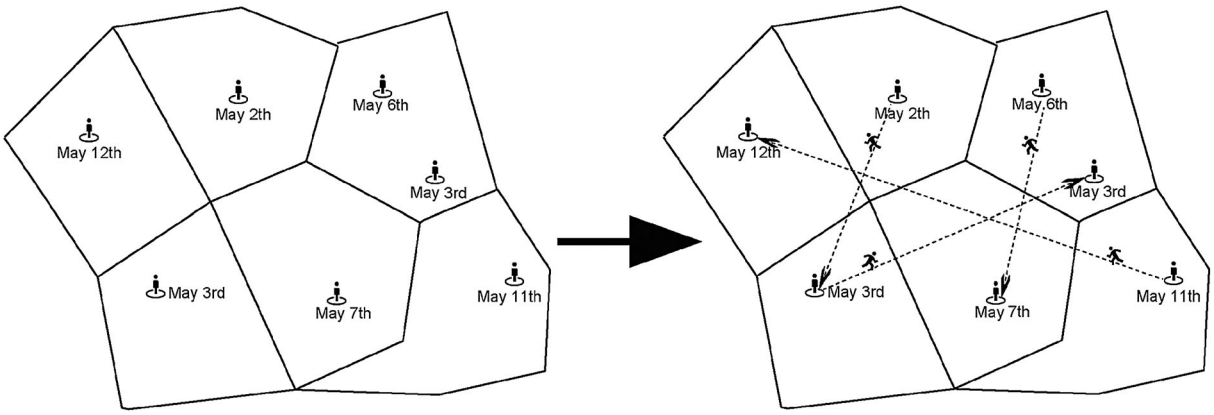

Figure 2. Definition of inter-city trips based on Weibo users' geo-tagged records.

Following Llorente, Garcia-Herranz, Cebrian, and Moro's procedure (2015) for generating Twitter users' inter-city travel, this paper assumes that a trip has occurred if the user has successively posted geo-tagged records in two cities within two successive days. The reason to apply two successive days as a time restriction is based on a couple of considerations: (1) the two-day duration ensures that Weibo users can travel between the city pair with the greatest distance – the maximum trip time is more than 10 hours – and have sufficient time to post geo-tagged records; while (2) adopting a longer time interval would reduce the reliability of deriving inter-city direct movements from successively posted records. Based on a hypothetical example in which a user posts seven geo-tagged messages in six cities within May, Figure 2 shows how the inter-city mobility network is constructed. The resulting dataset includes more than 0.78 million records of inter-city trips among the 89 statutory cities, which is 38.32% of all generated mobility records that consist of inter- and inner-city trips.

Our geo-tagged Weibo posts only represent a sample of all Weibo records, and Weibo users only represent a sample of the overall population. To test the representativeness of Weibo records, we first check the demographic composition of Weibo users in terms of gender and age. Given the concern of personal privacy, our data do not contain users' socio-economic characteristics. We refer to the Weibo users annual statistic report issued by Sina Corp, which shows that Weibo users are predominantly found among younger groups (the group aged between 17 and 33 occupies 83% of total users) and the gender proportion is balanced. However, our study assesses the overall formation of human movements at an aggregate level, and we see no reason why this bias towards youth groups will result in a meaningful regional bias. Recent studies have suggested that social media sampling is suitable for representing aggregated human activity, particularly in cases in which individual human mobility data are sparse in China and many other countries (Mayer-Schönberger & Cukier, 2013; Wu et al., 2016). However, in order to emphasize further the validity of the Weibo data, we investigate the spatial representativeness of Weibo sampling using population distribution data from the *Statistical Yearbooks* of Shanghai, Jiangsu, Zhejiang and Anhui provinces (2014) as a benchmark. Figure 3 shows high correlations between each city's population and its geo-tagged Weibo users as well as geo-tagged Weibo records, with correlation coefficients of 0.94 and 0.95 ($^*p < 0.001$), respectively.

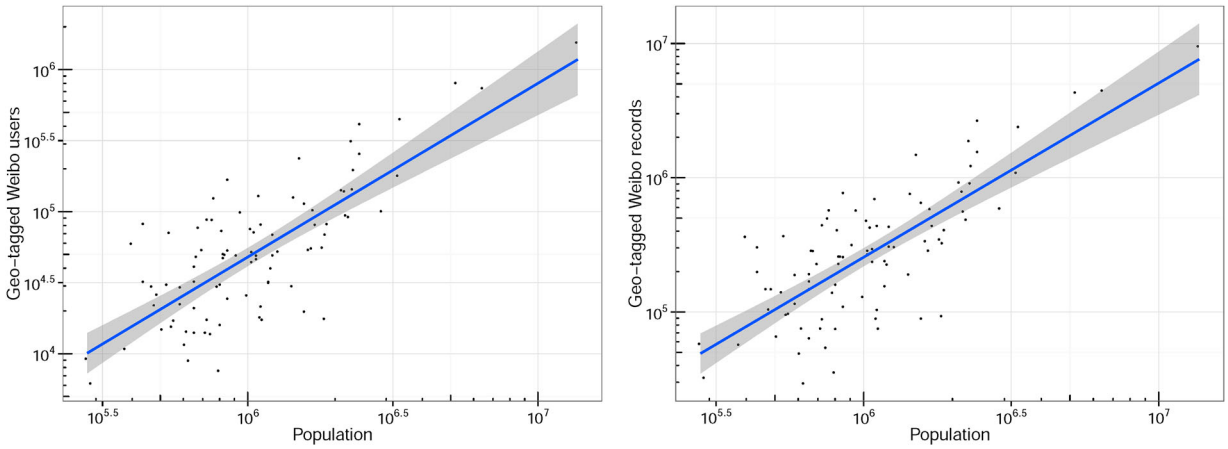

Figure 3. Correlations between cities' population, their number of geo-tagged Weibo users and the number of geo-tagged Weibo records.
Note: We normalized these variables using a log transformation to alleviate the skewness in their distributions. The grey area surrounding the solid line shows the 95% confidence interval.

Regionalization based on inter-city human movements

The purpose of this section is to divide the YRD into smaller sub-regions in which cities are more strongly connected to one another. The community detection approach in network science, which is used to partition a network into clusters with stronger connections, is a useful tool to achieve this regionalization. This paper employs the community detection approach known as the fast greedy method (Clauset, Newman, & Moore, 2004). The method is a hierarchical agglomeration technique that operates by optimizing Newman–Girvan modularity (Girvan & Newman, 2002).[6] Because many networks are characterized by hierarchically nested structures, this method facilitates identifying these nested communities using stepwise detections. In this research, the community detection procedure was performed on the R statistical platform using the igraph package (Csardi & Nepusz, 2006). Four communities were detected at the first detection (see the results section). However, the four generated communities seem to fail to reveal the fragmented space of the YRD at a smaller scale (for instance, the YRD consists of 12 dialect zones, 15 landform pattern zones and 11 CSLRP zones). To address this issue, we further detected the (sub-)communities within the first-step communities. Thus, the resulting regionalization is a two-tier partition.

Comparing interaction- and attribute-based regionalizations

Comparing two regionalization can be achieved through an assessment of the probability that a pair of cities in the same group in a regionalization setup also belong to the same group in the other regionalization. To this end, we propose the following criterion for assessing this probability:

$$F(P, P') = \frac{N1}{NP} \tag{1}$$

where $F(P, P')$ represents the correlation index between the attribute-based regionalization (P) and the interaction-based regionalization (P'); $N1$ represents the number of city pairs in the same group under both P and P'; and NP represents the number of city pairs within the communities under P. This criterion awards a value of 0 for two completely unrelated partitions. However, the maximum possible value of $F(P, P')$ is dependent on the possible maximum of $N1$. If the possible maximum of $N1$ is smaller than NP, the possible maximum of $F(P, P')$ is less than 1. To facilitate our comparisons, we therefore report normalized values of $F(P, P')$ in such a way that the values are in the range [0, 1], where 0 indicates absolutely unrelated and 1 indicates perfect correlation. The normalization is given by the following:

$$F'(P, P') = \frac{F(P, P')}{F_{\max}(P, P')} \tag{2}$$

$$F_{\max}(P, P') = \frac{\mathrm{Min}(NP, NP')}{NP} \tag{3}$$

where $F'(P, P')$ represents the normalized correlation index; $F_{\max}(P, P')$ represents the possible maximum of $F(P, P')$; NP' represents the number of city pairs within the groups under P'; and $\mathrm{Min}(NP, NP')$ represents the minimum of NP and NP'. Applying formulas (1) to (3) allows for a comparison of the interaction-based regionalization with the various PECA regionalization to be made.

Benchmarking the intra-connectivity of sub-regions

Finally, to understand further the relationship between interaction-based regionalization and the PECA regions, we benchmark the intra-regional connectivity of the putative sub-regions in the attribute-based regionalization using a two-step approach.

First, we calculate the dominance index of the intra-connectivity (DI) of each sub-region. This index is formulated as the ratio between the average strength of the inter-city connections within the sub-region and the average strength of the outward connections of the involved cities:

$$DI = \frac{Intra\text{-}connectivity}{Extra\text{-}connectivity} \tag{4}$$

Second, we benchmark the dominance index of the intra-connectivity of each sub-region against the average dominance of the intra-connectivity of the sub-regions of the interaction-based regionalization:

$$DI' = \frac{DI}{\sum_{j=1}^{J} \frac{DI_j}{J}} \tag{5}$$

where DI' is the benchmarked intra-connectivity; and DI_j is the dominance index of the intra-connectivity of sub-region j in the interaction-based regionalization. A value > 1 indicates that the degree of regional integration of the sub-region is stronger than the average integration scenario of the interaction-based regionalization, while a value < 1 indicates that the degree of the regional integration of the sub-region is less than the average integration scenario of the interaction-based regionalization.

RESULTS

The YRD's regionalization: spatial adjacency and expected patterns

This section reports the general patterns of the interaction-based regionalization. Figure 4 maps the two-tiered regionalization of the YRD. The first step in the detection produces four sub-regions, which are simply termed the central, northern, western and southern sub-regions for reasons of clarity. The iterative detection for these sub-regions produces 14 second-tier sub-regions, which are labelled according to their major cities (i.e., prefecture-level cities). The average modularity of these partitions ($\bar{M} = 0.31$) is indicative of the strong cluster structures in the resulting sub-regions (Newman, 2006).[7] The robustness of this result is tested by comparing the outcomes obtained using the Walktrap and MultiLevel algorithms. The outcomes show that the communities obtained from

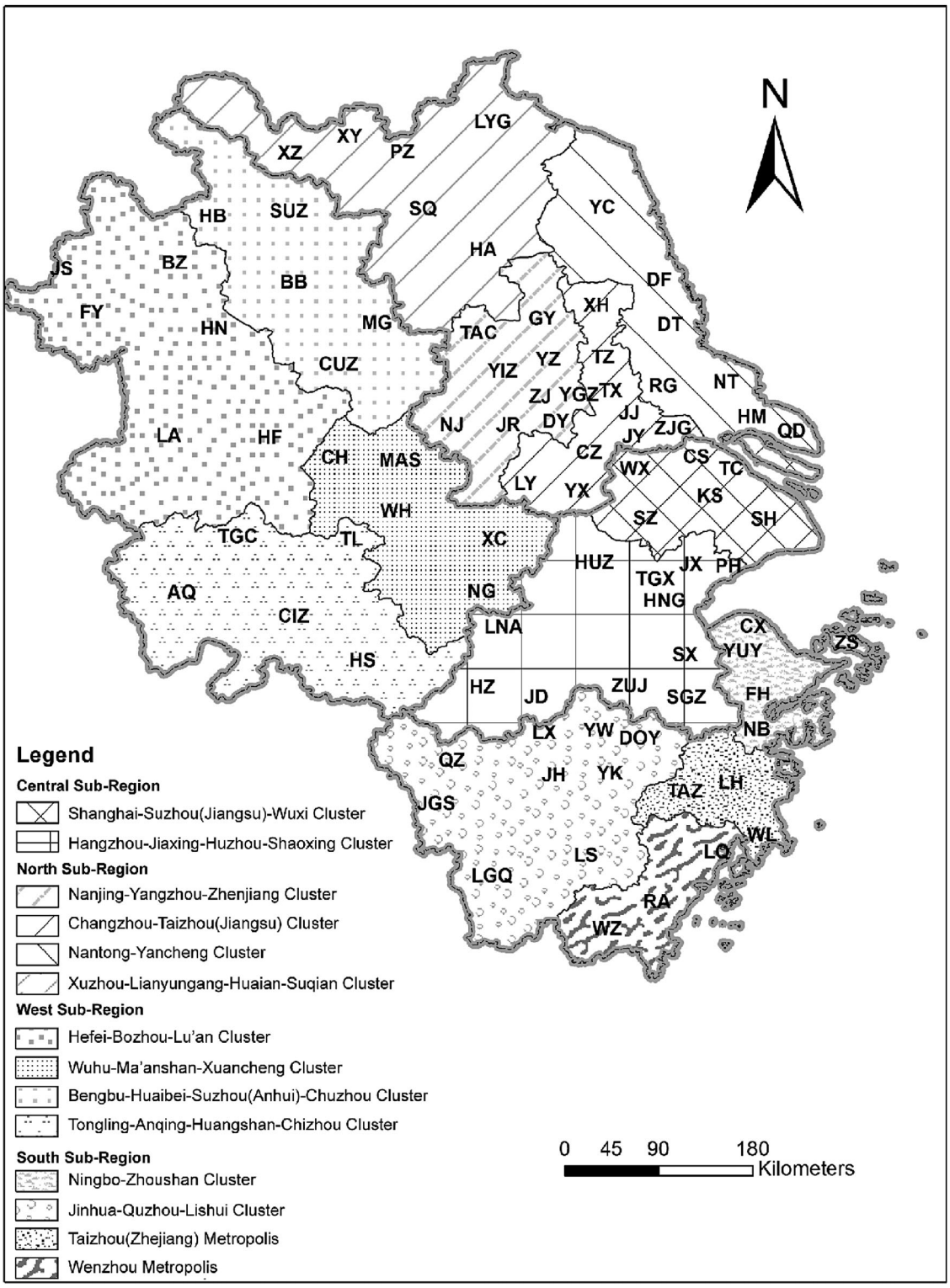

Figure 4. Interaction-based regionalization of the Yangtze River Delta.

the different methods are highly similar (see Appendix B in the supplemental data online).

Two initial observations can be made based on the regionalization. First, the cities within the same communities are perfectly spatially adjacent. If one bears in mind that the generated partition is based on the network's topology rather than considering the spatial attributes of cities, the complete spatial adjacency within all communities provides convincing evidence for the fundamental effect of distance and spatial adjacency on inter-city connections although the nature of the geographical patterns is of course that neighbouring territorial units have closer connections (cf. Tobler, 1970).

Second, the overall pattern is unsurprising. Except for the central sub-region, the territories of the first-tier sub-regions are generally in accordance with provincial borders,

while the second-tier sub-regions also correspond to pre-existing, integrated socio-economic clusters. For instance, the Nanjing–Zhenjiang–Yangzhou cluster, which was established by local governments over 10 years ago and is now an integrated city cluster (*Ning-Zhen-Yang Tongchenghua* in Chinese), is clearly indicated. The *Oujiang* dialect zone, where non-natives are barely able to understand the local language because of its tonal complexity, stands out as an individual community. In addition, the *Huanghuai* Plain, where cities share a similar *Han* cultural background and industrial structure and have suffered the same historical catastrophes, such as repeated massive Yellow River floods and avulsions (which strengthened the emotional affinity and self-identification of the region's inhabitants; Zhou, 1993), is reproduced in this regionalization. However, to what extent is the proposed regionalization systematically in line with the PECA partitions? The next section presents a quantitative analysis of this question.

Comparing different regionalization

Table 1 summarizes the correlation indices between the interaction-based regionalization and the different PECA regionalization. Generally, the four PECA regionalization exhibit obvious correlations with the pattern of inter-city connections that are reflected in the interaction-based regionalization (with correlation indices over 0.45, meaning that over 45% of the city pairs are in the same group under two partitions). Most notably, administrative boundaries have the strongest influence on inter-city connections, with a correlation index of over 90%. In addition, these correlations vary across the sub-regional tier. For instance, CSLRPs have a closer connection to the first-tier communities (with a correlation index of 0.84), while the connection strength largely decreases with the second-tier communities (with a correlation index of 0.48). Thus, the effects of the PECA spaces on regional integration should be separately discussed at different scales. The correlation indices are the evidential basis on which the majority of analyses are based in the following section.

Table 1. Correlation indices between the interaction- and attribute-based regionalizations.

	Interaction-based regionalization	
Attribute-based regionalization	**First-tier communities**	**Second-tier communities**
Provincial territories	0.90	0.96
Prefecture-level territories	0.91	0.90
Dialect zones	0.56	0.75
Sub-dialect zones	0.45	0.63
Landform zones	0.70	0.52
Central state-led regional planning territories	0.84	0.48

Parallels and differences with the PECA regionalization

This section identifies the main similarities and differences between the interaction-based regionalization and the PECA regionalization by assessing (1) 'cross-(administrative) border cities', (2) the intra-connectivity of landform regions, (3) the intra-connectivity of dialect regions and (4) the intra-connectivity of the urban regions designated by the CSLRPs.

Cross-(administrative) border cities

The cross-(administrative) border cities are singled out using the following criteria: if a city and more than half of the cities within the same community belong to different provinces, the city is defined as a cross-provincial border city; if a county-level city and its superordinate prefecture-level city belong to different communities, the county-level city is defined as a cross-prefecture border city. Figure 5 maps these cities.

The first observation is that the central sub-region in the generated regionalization, which consists of the key cities that surround Shanghai, results in most of the provincial border-crossing cities being located within the Jiangsu and Zhejiang provinces. It also creates the cross-prefecture borders for Jiangyin, Zhangjiagang and Yixing, which belong to the Suzhou and Wuxi prefecture cities with respect to administrative relationships but are not placed in the central sub-region. This 'prefecture-border breaking' can be attributed to two factors. On the one hand, without exception, these three cities are the most economically successful county-level cities in China. Their outstanding economic performance has enabled them to accumulate greater financial power and administrative competency and thus decreased their dependence on their superordinate prefecture-level governments. On the other hand, these cities are a long commuting distance from Shanghai (over two hours by car) and lack direct high-speed railway connections. Their counterparts in this region, such as Taicang and Kunshan, are located within commuting distance of Shanghai and attract many Shanghai workers who wish to reside in the area. Therefore, these cities are tightly grouped, as can be observed in the generated regionalization. Second, Tianchang breaks both the provincial and prefecture borders. Its 'border breaking' can be understood from two perspectives. On the one hand, geographically, Tianchang – nicknamed 'the eastern door of the Anhui province' – is deeply embedded in the territory of Jiangsu province. More specifically, it is closer to Yangzhou – the adjacent prefecture-level city in Jiangsu province – than to its superordinate prefecture-level city, Chuzhou. On the other hand, historically, Tianchang was part of Yangzhou for a long period during the Tangsong dynasty (618–1279 CE). During that period, the dialect of Tianchang and Yangzhou formed. The combination of the spatial and historical factors as well as the more advanced economy of Yangzhou has resulted in closer connections between Tianchang and Yangzhou. Third, the 'border breaking' of Chaohu

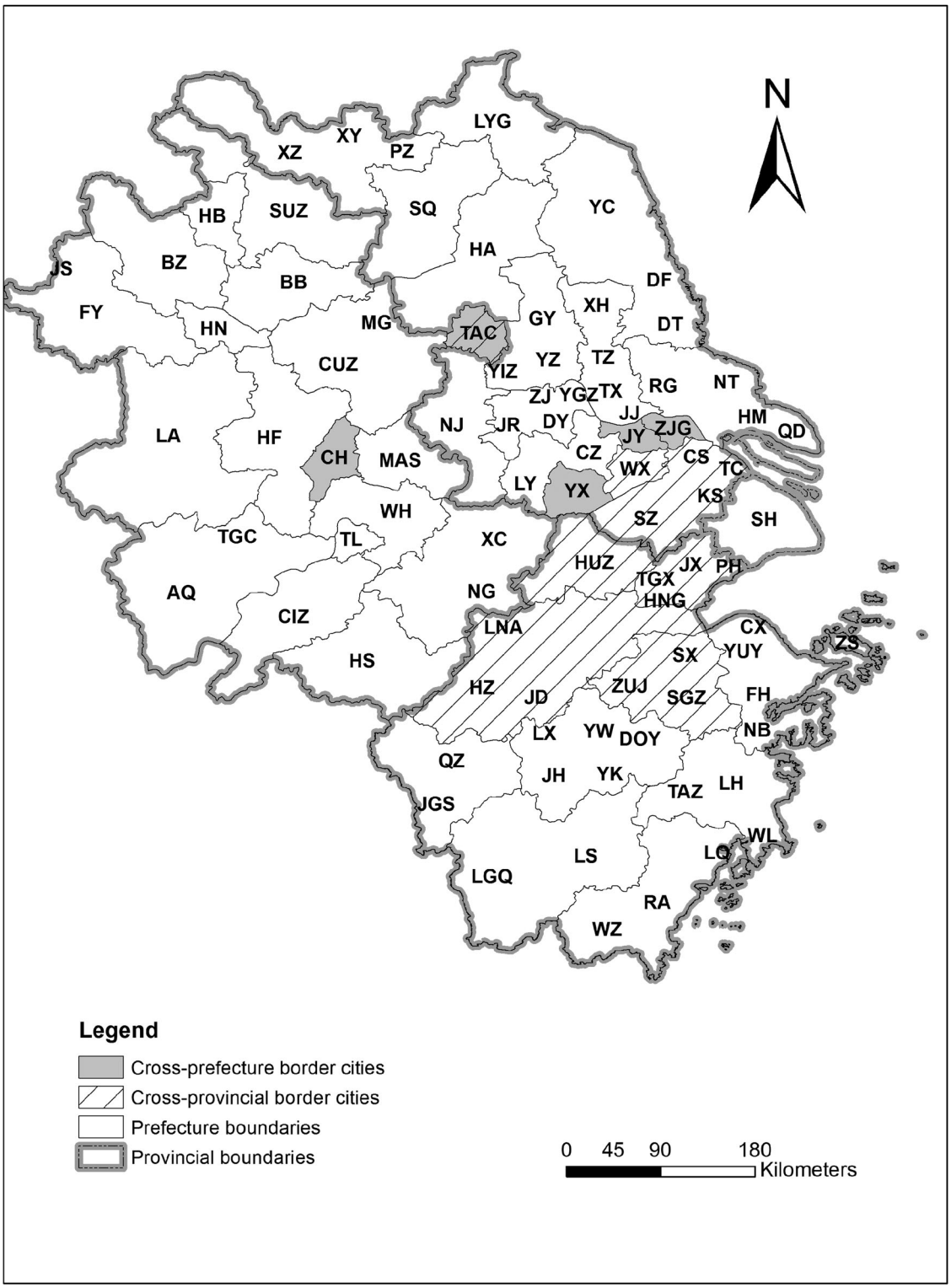

Figure 5. Cross(-administrative) border cities within the Yangtze River Delta.

can be attributed to the administrative adjustment implemented by the Anhui province government. In 2011, the original prefecture-level city of Chaohu was split into three parts. One part (Juchao district) was renamed (new) Chaohu and was merged into Hefei City as a county-level city. That is, the current Chaohu is artificially designated as part of Hefei. Its 'border breaking', which appears in the generated regionalization, is thus the product of administrative annexation.

Restrictions of landforms on inter-city connections

Table 2 presents the benchmarked intra-connectivity for the 15 landform regions. The main point to make here is that the plains and basins have stronger intra-connections than the regions dominated by hills and mountains. In particular, the Sunan Plain and the Southeast Coastal Plain have even stronger intra-connections than the average integration level of the generated sub-regions. It is important to remember that intra-connectivity is a relative measure,

Table 2. Benchmarked intra-connectivity (*DI'*) for the 15 landform regions.

Rank	Landform regions	DI'	Rank	Landform regions	DI'
1	Sunan plain	1.87	9	Zhebei plain	0.55
2	Southeast coastal plain	1.64	10	Jianghuai hills	0.40
			11	Jianghuai plain	0.36
3	Zhenan mountains	0.84	12	Zhedong hills	0.34
			13	Wannan mountains	0.17
4	Jinqu basin	0.79	14	Wanxi-Dabie mountains	0.07
5	East coastal plain	0.75	15	Zhexi hills	0.02
6	Huanghuai plain	0.71			
7	Riverside plain	0.62			
8	Huaibei plain	0.58			

which is benchmarked by comparing it with the outward connectivity of the involved cities. Thus, the measure implies that plains and basins have more intra-connections than outward connections, while hilly and mountainous areas have more outward connections than intra-connections. In addition to the fact that plains/basins have relatively denser transport networks and the hills/mountains having relatively sparser networks, hilly and mountainous areas tend to have more connections with external cities, which help them to access larger markets and economic entities. However, the Zhenan Mountain region, in which Longquan and Lishui are located, is a major exception and has stronger intra-connectivity, which is the result of the strong administrative relationship between the cities.

Restrictions of dialects on inter-city connections

Table 3 presents the benchmarked intra-connectivity for four dialect regions and 10 sub-dialect regions. It can be observed that the sub-dialect regions have more intra-connectivity than the dialect regions. At the scale of the dialect regions, the Central Plains Mandarin and Wu Chinese regions are the two most intra-connected regions. The high integration of the two dialect regions can be attributed to their unique geographic and economic positions in the YRD. The Central Plains Mandarin region, which is located at the YRD's northern edge, has closer connections to the Central Plains region in terms of culture and economy than with the other parts of the YRD. Additionally, the Wu Chinese region is indisputably the spatial and economic core region with closer inter-city connections (the YRD was once viewed as equal to the Wu Chinese region in history, although the geographical scope of the YRD has largely extended beyond that geographic scope of the Wu Chinese region) (Wang & Sun, 2015). At the scale of the sub-dialect regions, the intra-connections of the Oujiang and Taizhou dialect regions are very evident. Their extremely strong intra-connectivity appears in the generated regionalization as two individual clusters. These two dialects are the most mutually unintelligible languages compared with other varieties of Chinese. Partly because of the distinct dialects, the locals possess a strong sense of identity and form tight, trust-based social networks (Wei et al., 2007).

Table 4. Benchmarked intra-connectivity (*DI'*) for the 11 designated urban regions through central state-led regional plans (CSLRPs).[a]

Rank	CSLRP	DI'	Rank	CSLRP	DI'
1	PWTSEZ	0.86	7	RPYRD	0.37
2	PSMDA	0.62	8	PDMRRD	0.31
3	PHUEC	0.58	9	RPNM	0.25
4	PITCDRSA	0.52	10	PZOEDDZ	0.22
5	PJCD	0.52	11	PCPER	0.22
6	PITDZWCB	0.40			

Note: [a]For the CSLRP codes, see Appendix A in the supplemental data online.

Assessment of the intra-connectivity of the urban regions designated by CSLRPs

Many government-designated urban regions (by means of CSLRPs) are considered 'arbitrary groupings' of nearby metropolitan areas rather than entities that reflect the actual integration of urban regions (Liu et al., 2016). Table 4 (for CSLRP codes, see Appendix A in the supplemental data online) presents the benchmarked intra-connectivity for 11 designated urban regions. The most obvious pattern is that in which the intra-connectivity of all urban regions is less than in the average integration scenario of the generated sub-regions. That is, the degree of the regional integration of these regions is relatively weak, at least in terms of human inter-city mobility. This view is consistent with Li and Wu's (2013, p. 145) argument in that 'the regional plan is manipulated by the local government to lobby for development rather than coordination'. Appendix C in the supplemental data online discusses these so-called 'arbitrary groupings' by investigating the process of grouping five

Table 3. Benchmarked intra-connectivity (*DI'*) for four dialect regions and 10 sub-dialect regions.

Rank	Dialect zones	DI'	Rank	Sub-dialect zones	DI'	Rank	Sub-dialect zones	DI'
1	Central Plains Mandarin	0.44	1	Oujiang dialect	2.97	6	Shangfu dialect	0.49
2	Wu Chinese	0.34	2	Taizhou dialect	2.90	7	Tairu dialect	0.44
3	Jianghuai Chinese	0.20	3	Huangxiao dialect	1.26	8	Taihu dialect	0.43
4	Hui Chinese	0.17	4	Jinqu dialect	0.71	9	Shangli dialect	0.34
			5	Xuhuai dialect	0.62	10	Hongchao dialect	0.25

Anhui province cities into the Central Plains Economic Region (CPER) – the least integrated urban region in Table 4.

DISCUSSION AND CONCLUSIONS

In this paper we investigated the regionalization of the YRD from the perspective of human day-to-day inter-city mobility. We conclude by discussing the key findings, some of which enhance our understanding of the YRD's formation, while others more generally relate to our understanding of the relation of 'network' and 'territory' in regional (re-)productions.

China's mega-city-regions are characterized by a range of spatial fragmentation processes in terms of physical, economic, cultural and administrative factors. Thus, the discussion of the generated regionalization for the YRD is rooted in the particular context of China's regional and urban development. Our research first established that administrative borders – particularly provincial borders – strongly affect inter-city connections. In addition, a small number of cities with strong economic performance, distinctive geographical and historical characteristics, and administrative annexation appear as 'cross-border' cities. We also discovered that the restrictions of rugged landform patterns and (unintelligible) dialects on regional integration remain significant. Moreover, by assessing the integrated degree of emerging regional (economic) alliances (created by multiple central state-led regional plans), we argued that the CSLRP regions are more or less the product of balancing administrative interests and thus have a relatively weak foundation for regional integration.

These empirical findings also invite reflection on regions caught between territory and networks (cf. Harrison, 2013). Based on the analyses of Weibo users' intercity mobility within the YRD, three observations can be made. First, we have shown that regional formations are bound through interconnected socio-economic activities. Second, the 'bounded' network organizations can be viewed as the product of the underlying territorially embedded spaces, albeit the effects of different physical, economic, cultural and administrative spaces on regional integration are distinct and interpenetrating. Third, the logic of 'regional path dependence' (Martin & Sunley, 2006) in economic geography seems to be relevant for understanding regional (re-)production. That is, the overall patterns of the interaction-based regionalization and the phenomenon of cross-border cities reveal the influence of often longstanding historical factors.

One policy implication of our research is based on the observation that, since the early 2000s, China has experienced a resurgence of domestic regionalism in the wider context of marketization and decentralization. Regional planning is increasingly proposed by multilevel governments, and the construction of various regional alliances has become part and parcel of urban development strategy. In the 'new type urbanization strategy' recently implemented by the central state, prompting the development of urban agglomerations is established as a normative objective of national spatial development. However, from the standpoint of local authorities, bundled development is not only a means to promote inter-city cooperation and pursue agglomeration externalities but also a vehicle for massive infrastructure investment. It also implies governance recognition by the central state. As a result, local governments scramble to sponsor and/or join these regional alliances. This research reminds policy-makers that there is a need to rethink whether cities grouped during the wave of regional-alliance construction are in fact rooted in tangible inter-city connections or only 'a forced marriage' for economic interests in reality. In addition, this research identifies a need for further research on how political barriers affect socio-economic flows in the Chinese context.

The research presented here has several limitations, which suggest methodological approaches for further research. One limitation relates to a concern for the representativeness of Weibo data. Although our data source has been widely recognized as producing valuable material for fine-grained geographical research, the data only include information provided by social media users. Recent studies suggest that the social media sampling of Facebook and Twitter is biased towards highly educated groups, urban dwellers and men (Hacklay, 2012; Hecht & Stephens, 2014; Li, Goodchild, & Xu, 2013; Stephens, 2013). In our research, an age bias towards a younger group could be noted. However, whether these potential biases of social media data sampling result in bias with respect to the estimated patterns of overall human activity is unclear. Although we investigated the validity of Weibo-based mobility by comparing our data with overall population distribution data, to establish the representativeness of social media users finer-grained research is required. In addition, this specific comment is obviously part of a broader debate on the pitfalls of using big data in urban-geographical research (Poorthuis, Zook, Shelton, Graham, & Stephens, 2016). Finally, apart from the data concerns, the research focuses on the network of human day-to-day inter-city movements, whereas it is clear that urban networks are multiplex phenomena (Burger, Van der Knaap, & Wall, 2014). Therefore, the need to examine other types of linkages through further research is required.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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SUPPLEMENTAL DATA

Supplemental data for this article can be accessed at https://doi.org.10.1080/00343404.2017.1334878

NOTES

1. In network science, a group of nodes that are more closely connected to one another than to the other nodes in their network is termed a 'community'. For reasons of clarity, the clusters of cities generated by the community-detection technique in this paper are referred to as 'communities'.
2. 'City' has two different meanings in China's urban system. One is a municipal unit that consists of urban districts and extensive counties and is literally translated as '*Shi*'. The other is an urbanized or metropolitan area that approximately corresponds to the concept of 'city' in Europe and the United States. Such areas are literally translated as '*Chengshi*'. In this paper, 'city' refers to the municipal unit (for additional detail, see Chan, 2007). In addition, statutory cities in China consist of municipality-, prefecture- and county-level cities, and the latter are under the administrative jurisdiction of prefecture-level cities (for additional detail on China's administrative divisions, see Ma, 2005).
3. Because our research object is cities, if a region has more than one landform, we unify physical landforms according to the landform of the urban centre. The partition according to dialects follows the same rule.
4. The official geographical scope of the Zhejiang ocean economic development demonstration zone in Figure 1 (d) does not include the counties in Hangzhou. This paper extended its scope to include the extensive counties of Hangzhou to maintain a consistent research scale.
5. The number of monthly active users registered within the YRD is calculated based on the data from the Weibo users annual statistical report of 2014 issued by Sina Corp.
6. Newman–Girvan modularity is a quality measure of the community structure of networks. It is calculated by comparing the edge density within modules with the edge density in a random distribution with the same number of nodes (for additional detail, see Newman, 2006).
7. The range of modularity is from −1 to 1, with positive values indicating the presence of community structure. Values within the range of 0.3–0.7 are typically considered to signify a strong cluster structure.

ORCiD

Weiyang Zhang http://orcid.org/0000-0002-8002-3207
Jianghao Wang http://orcid.org/0000-0001-5333-3827

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