The geographical patterns of Chinese liquors during 1995–2004

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1. Introduction

Fermentation products, such as wine, whisky, vinegar, and Chinese liquor, have specific geographical signals and their unique brands are generally produced only in specific areas (Barham, 2003; Ozbek & Akman, 2016; Shen, 2012). Local biophysical environments are seen as the cause of this phenomenon, because these products are produced through chemical–biological processes of natural fermentation which depend on local micro-climate, chemical compounds and on the micro-flora provided by the biophysical environments (Frankel et al., 2012; Li et al., 2017; Martiny et al., 2006; Wu, Yu et al., 2015). Previous studies on fermented beverages have revealed that the chemical compounds and taste of fermented beverages are highly related to their geographical origins (Berna, Trowell, Clifford, Cynkar, & Cozzolino, 2009; Gougeon et al., 2009; Jiang, Xiao, Ning, Jia, & Liu, 2013; Masuda et al., 2010; Mena, Cabrera, Lorenzo, & Lopez, 1996; Möller, Catharino, & Eberlin, 2005; Pohl, 2007; Rodrigues et al., 2011; Yu, Zhou, Fu, Xie, & Ying, 2007).

Chinese liquor, or Baijiu in Chinese, is a distilled liquor mostly derived from fermented sorghum grains (Zhu et al., 2007). It is a popular alcoholic beverage with over 10 billion liters consumed annually (Cheng, Fan, & Xu, 2014). Chinese liquors vary greatly in production, quality, and taste. They can be divided into three major taste types, namely soy-sauce-, strong-aromatic-, and light-aromatic-flavored liquors (Yu, 2010). These different taste types exhibit a characteristic geographical distinction (Xiao, Yu, Niu, Ma, & Zhu, 2016). Moreover, most well-known liquor brands are produced only in a few specific locations. The best strong-aromatic-flavored liquors are only produced in southernmost Sichuan province and the best soy-sauce-flavored liquor is produced only in Maotai, a town in northern Guizhou province (Shen, 2012). In addition, the provinces of Sichuan, Shandong, Henan and Jiangsu, for instance, produce over 50% of the Chinese liquors (Figures A1 and A2 (see Supplementary material)). While biophysical factors are dominant factors contributing to the geographical distribution of liquors (Li et al., 2011; Liu et al., 2012), socioeconomic factors, as fundamental factors that determine the development of an industry, also constitute important elements underlying the development of the Chinese liquor industry (Jiang, Luo & Zhao, 2015; Skees, 1991).

Many studies concerning Chinese liquors have focused on the floristic composition and function of microorganisms in the fermentation process (Hu, Du, & Xu, 2015; Li et al., 2016; Zhu et al., 2007), ZaoPei (mash that has already finished the fermentation process) (Chen, Wu, & Xu, 2014; Li et al., 2011; Zhang et al., 2007), fermentation starters (Zheng et al., 2012), and components of liquors (Fan & Qian, 2006a, 2006b; Li et al., 2009; Zhu et al., 2016). However, few of these studies have focused on the impacts of local biophysical environments on the geographical distribution of Chinese liquors. Some studies have focused on the biophysical environments of Chinese liquors (Figures A1 and A2 (see Supplementary material)).
2006b). Using statistical data of yield, sales revenue, total profit, etc., researchers have qualitatively described the distribution of Chinese liquors at the provincial level (Fang, 2009; Yang, 2009). Jiang et al. have analyzed changes of the Chinese liquor yield and output value during 2000 and 2014 at national scale, and examined the management situations changes of the primary Chinese liquor manufacturers from 2009 to 2013 (Jiang, Luo & Zhao, 2015). Qian Li studied the evolution of three industrial clusters of liquor production in Sichuan and presented yields, manufacturers, and liquor brands (Li, 2012). Finally, Yang and Jiang have analyzed the main factors, such as geological and water environment influencing the distribution of Chinese liquor in Chishui River Basin, Guizhou (Jiang, Chen, Xiao, Ning, & Jia, 2013; Yang, 2014). There are few geographical studies concerning Chinese liquors on national and provincial scales. Unlike the geography of wine, which is well studied and understood (Dougherty, 2012; White, 2015; Wilson & Beazley, 1999), the geography of Chinese liquors is inadequately studied and poorly understood. Therefore, the objective of the present study is to reveal the spatial distributions of Chinese liquors and to explore the effect of the geographical environment on the regional differences of Chinese liquors at prefectural level.

2. Materials and methods

2.1. Chinese liquor data

There are many economic indicators regarding Chinese liquors in national statistical data, including yield, gross industrial production, consumption, number of manufacturers among others (Wang, 2013; Yang, 2011). In the present study, we used the number of manufacturers to study the geographical patterns of Chinese liquors, because these data are available at the prefectural level. Information on liquor manufacturers, including geographical location, year of establishment, and state of the business was extracted from the directory of Chinese liquor enterprises completed in 2004 (https://goumai.mingluji.com/node/80) In total, 6840 records of active businesses were extracted from the total 8516 records. The total number of manufactures was calculated at national and prefectural level from 1995 to 2004. This study period is considered as critical to the management situations changes of the primary Chinese liquor yield and output value (Fang, 2009; Yang, 2009). Jiang et al. have analyzed changes of the Chinese liquor yield and output value during 2000 and 2014 at national scale, and examined the management situations changes of the primary Chinese liquor manufacturers from 2009 to 2013 (Jiang, Luo & Zhao, 2015). Qian Li studied the evolution of three industrial clusters of liquor production in Sichuan and presented yields, manufacturers, and liquor brands (Li, 2012). Finally, Yang and Jiang have analyzed the main factors, such as geological and water environment influencing the distribution of Chinese liquor in Chishui River Basin, Guizhou (Jiang, Chen, Xiao, Ning, & Jia, 2013; Yang, 2014). There are few geographical studies concerning Chinese liquors on national and provincial scales. Unlike the geography of wine, which is well studied and understood (Dougherty, 2012; White, 2015; Wilson & Beazley, 1999), the geography of Chinese liquors is inadequately studied and poorly understood. Therefore, the objective of the present study is to reveal the spatial distributions of Chinese liquors and to explore the effect of the geographical environment on the regional differences of Chinese liquors at prefectural level.

2.2. Climatic and socio-economic data

We used annual mean temperature and annual precipitation (1981–2010) provided by the National Meteorological Information Center (http://data.cma.cn/) to calculate perennial mean temperature (PMT) and average annual precipitation (AAP) (Figure A3 (see Supplementary material)). These two indicators can represent the climatic conditions of a region (Dijkstra & Neelin, 1995; Safford, 1999). Climatic data are available for each prefecture-level administration unit, except for Chizhou in Anhui province, Jayuguan prefectures in Gansu province, Hong Kong, Macao, and Taiwan.

Two socio-economic indicators, gross domestic product (GDP) and human population density (HPD), were used to represent regional socio-economic conditions (Figure A3 (see Supplementary material)), because they are internationally recognized metrics (Cinner, Graham, Huchery, & Macneil, 2013; Cutter & Finch, 2008; McDonald & Temple, 2010). They were obtained from the China Statistical Yearbook for Regional Economy and China City Statistical Yearbook issued by the National Bureau of Statistics of the People’s Republic of China. Socio-economic data are available for each prefecture-level administration unit. There are no data on Hong Kong, Macao, and Taiwan.

2.3. Eco-geographical regionalization

We used eco-geographical regionalization in China to ensure the topographic features of Chinese liquor producing regions (Figures 1 and 2 (Main Map). The dataset is provided by the Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn).

2.4. Spatial autocorrelation analysis

This is a method that is commonly applied to measure the spatial distribution characteristics of a physical or ecological phenomenon by using the Moran’s index statistics (Dormann et al., 2007; Ord & Getis, 1995). GeoDa software was adopted to calculate these statistics to measure spatial dependence (Global Moran’s I) and the local variability and similarity (Local Moran’s I) of Chinese liquor manufacturers (Fischer & Getis, 2010). The two statistics were calculated according to the following equations.

Global Moran’s I can be expressed as follows (Lichstein, Simons, Shriner, & Franzreb, 2002):

\[ I = \frac{n \times \sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i \sum_j w_{ij} (x_i - \bar{x})^2}, \]

where \( w_{ij} \) is the weight between units \( i \) and \( j \), \( x_i \) and \( x_j \) are the values for units \( i \) and \( j \), \( \bar{x} \) is the mean value of all units, and \( n \) is the number of units.
where \( n \) is the number of units; \( x_i \) and \( x_j \) are the values of Chinese liquor index variable at locations \( i \) and \( j \); \( \bar{x} \) is the mean of \( x \); \( w_{ij} \) is the weight matrix that defines the proximity between \( i \) or \( j \) and their adjacent units based on contiguity relations. The value of Global Moran’s \( I \) varies mostly from \(-1\) to 1. Under the null hypothesis of no spatial autocorrelation, \( I \) has an expected value near zero, with positive (negative) values indicating positive (negative) spatial autocorrelation. The significance of Global Moran’s \( I \) can be tested based on their standardized scores (\( Z \)) (Karun, Puranik, & Binu, 2015). Spatial autocorrelation is significant at the .05 confidence level when \(|Z| > 1.96\); or at the .01 confidence level when \(|Z| > 2.54\) (Wang, Luo, & Liu, 2015).

Local Moran’s \( I \) for an observation \( i \) may be defined as follows (Anselin, 1995):

\[
I_i = z_i \sum_j w_{ij}z_j,
\]

where the observation \( z_i \), \( z_j \) are the differences between the values of Chinese liquor index variable \( x_i \), \( x_j \) and the mean \( \bar{x} \), respectively. \( w_{ij} \) is the spatial weights matrix. A positive value of Local Moran’s \( I \) with a statistical significant at .05 or .01 confidence level implies that the location has similarly high or low values with its neighbors (High–High/HH and Low–Low/LL clusters); a negative value of Local Moran’s \( I \) occurs when dissimilar values occur near one another (High–Low/HL and Low–High/LH outliers) (Figure 2) (Main Map). The original data should be in normal distribution before using this method. We used the Rank Cases in SPSS version 19 to transform Chinese liquor data into normal scores before statistical analysis (Figure A4 (see Supplementary material)) (Gastwirth, 1977; Tiefelsdorf, 2002).

2.5. Geographically weighted regression

To explore the spatial relationships among the geographical distribution of Chinese liquor manufactures and climatic and socio-economic indicators, we used the geographically weighted regression (GWR). Compared with traditional Ordinary Least Squares (OLS), GWR can effectively consider spatial autocorrelation and spatial non-stationarity issues through embedding location data into the regression parameters between dependent and independent variables (Brown et al., 2012; Fotheringham, Brunsdon, & Charlton, 2002). The results predicted the relationships among...
environmental variables and the Chinese liquor indicators were better for GWR models than for OLS by use of ArcGIS 10.2 (Table A3 (see Supplementary material)). The GWR model was calculated according to the following equation (Tu & Xia, 2008):

\[
Y_j = \beta_0(u_j, v_j) + \sum_{i=1}^{n} \beta_i(u_j, v_j)x_{ij} + \epsilon_j, \quad (3)
\]

where \( Y_j \) is the dependent variable, \((u_j, v_j)\) denotes the coordinates for location \( j \), \( \beta_i(u_j, v_j)\) denotes the local regression coefficient for independent variables \( x_i \) at location \( j \), \( \beta_0(u_j, v_j) \) and \( \epsilon_j \) are the intercept and error term, respectively. \( \beta_i(u_j, v_j) \) is estimated from Chen et al. (2016):

\[
\beta_0(u_j, v_j) = \sum_{k=1}^{p} w_{jk} \left( Y_k - \beta_0(u_j, v_j) - \sum_{i=1}^{n} \beta_i(u_j, v_j)x_{ij} \right)^2, \quad (4)
\]

where \( w_{jk} \) is the weight which denotes the distance decay function for location \( j \) and \( k \), with the assumption that observations closer to sample point \( j \) have a higher influence on local regression parameters. \( w_{jk} \) can be calculated using many method, we use the Gauss function in this study (Brunsdon, Fotheringham, & Charlton, 2002; Chen et al., 2016):

\[
w_{jk} = \exp \left( -\frac{d_{jk}^2}{b^2} \right), \quad (5)
\]

where \( d_{jk} \) is the distance between location \( j \) and \( k \), \( b \) is the kernel bandwidth. Fixed and adaptive bandwidths are provided in ArcGIS 10.2. We found that the test results were better by using fixed bandwidth method (Table A2 (see Supplementary material)).

3. Results

3.1. Geographical distribution of Chinese liquor manufacturers

There were obvious regional differences of DLM. While DLM in many prefectures increased from 1995 to 2004, the striking regional pattern did not change (Figure 1) (Main Map). Most liquor manufacturers were located on the eastern side of the Hu Line, an

![Figure 2. Distributions in local spatial autocorrelation of density of liquor manufacturers (DLM) in China in 1995 (a), 2000(b), and 2004 (c), the eco-geographical regionalization (d) provides the locations of the clustering regions and non-clustering regions of DLM. The distributions of local spatial autocorrelation of DLM show significant areas with \( p \leq 0.05 \) as yellow, orange, red and grey, and no significant areas as white. HH and LL equal the spatial clusters, LH and HL equal the spatial outliers. The figure was created by using ArcGIS version 10.2.](image)
important geo-demographic demarcation line which divides China into two regions (southeast and northwest). The Hu Line runs from Heihe in northeastern Heilongjiang to Tengchong in southwestern Yunnan in China and is used to describe the general population distribution in China (Hu, 1935; Hu & Zhang, 1986). The highest DLM, found in the North China Plain and in the Sichuan Basin, did not change (Figure 1) (Main Map). During the study period, there was a significant positive autocorrelation of DLM in terms of Global Moran’s I ($I \geq 0.47, Z \geq 13.70$), which demonstrates that the distribution pattern of DLM was clustered in statistics (Table 1).

Temporal changes in local spatial autocorrelation of DLM from 1995 to 2004 revealed no changes in the high–high (HH) and low–low (LL) clusters (Figure 2) (Main Map). The HH regions were mostly located in the North China Plain and in the Sichuan basin. Most LL regions roughly covered the western side of Hu line and the remaining ones were distributed in the joint of Guizhou Plateau, Yunnan Plateau, Nanling Mountains, and Fujian-Guangdong-Guangxi Hills and Plain in the eastern side of Hu line (Figure 2) (Main Map).

### 3.2. The relationships among climatic and socio-economic variables and DLM

The effects of the climatic variables on DLM were different in space and were enhanced with time (Figure 3). PMT has the largest contributions to DLM. The sign of coefficients of PMT changed from negative in the western side of the Hu Line, northeast China, and Fujian-Guangdong-Guangxi Hills and Plain to positive in southwestern and the eastern China. The coefficients of PMT were largest in Sichuan Basin and Guizhou Plateau and increased in North China Plain from 1995 to 2004. The positive AAP coefficients were found to be high in the regions, where AAP is less than 400 mm (Figure A3 (see Supplementary material)), while the negative AAP were higher in the areas with relatively moderate precipitation than other regions. The influences from HPD and GDP, respectively, showed similar feathers in space and were not continually enhanced or weakened with time (Figure 3). The positive and negative coefficients among DLM and social-economic variables were larger in less populated and less developed areas than in densely populated and better developed areas.

These results suggested that temperature and precipitation played more important roles for the geographical pattern of Chinese liquors compared to socio-economic conditions. At least, the relatively temperate climate is dominant factors for the HH clusters.

### 4. Discussion and conclusions

There are distinct HH DLM areas and LL DLM areas at prefectural level (Figure 2). According to the Köppen climate classification (Zhu & Li, 2015), HH DLM areas are concentrated in temperate/mesothermal climates, while LL DLM areas are found in climates other than temperate. The results of GWR model also demonstrated the phenomenon (Main Map). Previous studies have also revealed approximately 55% of high-quality wine-producing areas in temperate/mesothermal climates (Jones, Reid, & Vilks, 2012; Peel, Finlayson, & McMahon, 2007). It is clear that fermented alcoholic beverages also have their own characteristic geographical distribution.

Concentration of high-quality fermented alcoholic beverages in temperate/mesothermal areas is probably associated with their natural fermentation process. Slow fermentation with low initial temperature proves, both experimentally and experimentally, to be crucial for producing high-quality fermented alcoholic beverages, especially for Chinese liquors (Cao, 2006; Shen, 2012). Studies indicate that fermentation at low temperatures boosts the activities of the yeast *Saccharomyces cerevisiae* Meyen ex E.C. Hansen. This yeast species is important for fermentation of alcoholic beverages and has a positive impact on the aromatic profile of beverages (Aguilera, Ranzel-Gil, & Prieto, 2007; García-Ríos, Querol, & Guillamón, 2016; Salvadó et al., 2016; Torija et al., 2003). The necessity of low temperatures, along with appropriate air humidity, restricts Chinese liquor production to specific regions and seasons. Generally, seasons other than summer are suitable production periods, because in summer high air and ground temperatures in many places are hardly suitable for slow fermentation, which requires a low initial temperature for liquor manufacturing (Sun et al., 2016; Zhu & Zhao, 2002). For instance, Fenjiu, the typical and best light-aromatic-flavored liquor (Wu, Zhu, Wang, & Xu, 2015), is produced primarily in two periods, from March to April, and from November to December. During these periods, both yield and quality are higher (Ren & Qu, 2014). The production cycle of the Guizhou Maotai, the typical and best soy-sauce-flavored liquor, often referred to as the ‘National Liquor’ (Zhu et al., 2007), is eight months from October through May (Shen, 2012). Due to the high temperature, liquor production ceases during July and August (Cui, 2002).

There are also obvious regional differences of taste for fermented alcoholic beverages in different parts of the moderate climatic regions. For example, Burgundy and Bordeaux, two of the world’s greatest centers of fine wine production and Appellation of Origin areas,
produce wines with different flavors (Lemaire & Kasserman, 2012). One reason is the difference of physical terroir, including climate, soil, and geologic bedrock, which leads to the differences of grape quality (Lemaire & Kasserman, 2012). Located in the transitional zone from Sichuan basin to Guizhou plateau, the Chinese Liquor Golden Triangle, a conspicuous clustering region of best-known and well-known liquor brands in China (Figure 2), produces two best distinct flavor types liquors (soy-sauce- and strong-aromatic-flavored types) (Huang & Liu, 2010). The physical environment, however, is very different in the production region of these two types of liquors (Zhang, 1988). The best strong-aromatic-flavored liquor is produced in a larger area, with hilly topography and southern-subtropical climate on the northern side of the Yangtze River. This region is characteristically humid and warm (Liu, Hu, Wang, Zeng, & Zhai, 2011; Tang et al., 2013). Humidity is high throughout the year (Tang et al., 2013). Comparatively, the best soy-sauce-flavored liquor is produced only in a specific small area of the Chishui River, characterized by high mountains and deeply dissected valleys. The area is also characterized by a hot-dry climate (Tang et al., 2012), and humidity is low during most of the production cycle (Liu & Tan, 2011). In addition, the best light-aromatic-flavored liquor, Fenjiu, is produced in Shanxi province, with warm temperate and semi-arid climate and sandy soil (Liang & Qi, 2002). The differences of these best Chinese liquors are attributed to different biophysical factors, especially climate, which affect grain properties, microorganism flora, and brewing techniques (Ge et al., 2008; Lu, Ding, & Qiu, 2009; Yu, 2010). Though it is still not adequately understood what specific biophysical factors are associated with specific taste types of Chinese liquors, it is well established that biophysical environments play an essential role in their production (Fan, Zhang, Wang, & Shi, 2004; Yu, 2010).

Figure 3. Local coefficients from perennial mean temperate (a–c), AAP (d–f), HPD (g–i) and GDP (j–l) for DLM during 1995 and 2004. The figure was created by using ArcGIS version 10.2.
DLM has increased considerably with rapid economic growth (Figure 1). Similarly, Chinese liquor yield, in either dominant producing regions or non-dominant producing regions, increased during different periods (1992–2000 and 2006–2010) (Figures A1 and A2 (see Supplementary material)). The highest DLM or liquor yield appeared both in the primary clustering regions and in the dominant producing provinces. These regions or provinces are found not only in better developed areas, but also in less developed areas (Figure A3 (see Supplementary material)). Therefore, economic growth can stimulate growth in production quantity but cannot cause any changes in the geographical distribution of Chinese liquors.

GDP increase was obvious from 1991 to 2004 in many administrative units at prefecture level (Figures A1 and A2 (see Supplementary material)). It was accompanied by changes in trade, supply, demand, and input–output that may account for quantity-wise of liquor manufacturers and liquor production across time in many prefecture-level administrative units (Hoover & Giarratani, 1984). However, there are also potential impacts of biophysical environments on the socio-economic development (Hoover & Giarratani, 1984; Strahler & Strahler, 1987). The regional differences of GDP and HPD between the southeastern side and northwestern side of China did not change much since the Hu Line was first proposed (Hu, 1935) (Figure A3 (see Supplementary material)), due to the limitation of the biophysical environments (Huang & Yang, 2012; Zhang, 2008). As a social and economic product, fermentation beverages are produced only in the areas where human inhabits. Quality Chinese liquors are a product of the biophysical environment, not of a certain region’s economic development. Despite its fastest economic growth and best development (Huang & Liu, 2010), South China does host neither larger HH clustering regions nor best known liquor manufacturers (Figure 2) (Shen, 2012), although the Chinese liquor industry is the most profitable among alcoholic beverages in China (Figure A5 (see Supplementary material)). This implies that socio-economic development has contributed to the growth of the Chinese liquor industry, but does not influence regional differences.

Geographical distribution patterns of Chinese liquor manufacturers are properly represented by their density, with no change in the clustering and only change in the number of manufacturers. Climate contributes to the spatial difference of Chinese liquors because warm climate favors the natural fermentation of liquor making microorganisms. Fast socio-economic development can stimulate the Chinese liquor industry in many regions but cannot change the geographical pattern of Chinese liquors. While the present study provides some new scientific understanding of the geography of Chinese liquors, more research on topics, such as geographical characteristics of taste types, the impacts of climate change on quality of Chinese liquors, is needed.

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Disclosure statement

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Software

The processing of data for the maps included several stages. The original data of Chinese liquors, perennial mean temperature and average annual precipitation, and gross domestic product and human population density were transformed into normal scores before statistical analysis by using SPSS version 19. Global Moran’s I and Local Moran’s I were calculated by the GeoDa software. The process of GWR model was conducted in the ArcGIS version 10.2. All figures were created by the ArcGIS version 10.2.

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