Quantization Studies on Sustainable Development in Chinese Urban Sprawl

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Abstract: This research explores “urban sprawl” to discover the reasons behind urban land-use changes and urban pattern transformations on a regional level. It begins with definitions of sprawl in Western and Eastern countries, then provides an adequate data analysis: collects related Index for urban sprawl and sustainable development for 15 top urban regions over 10 years (1999, 2004, and 2009), indicates which parameters can be considered as indicators for sustainable development in urban sprawl in China, and points out how these parameters affect the process of urban sprawl in the major cities in China.

Keywords: Urban sprawl, Sustainable development, Urbanized area, Land use

1. Background

Urban sprawl is usually seen as having diverse negative effects for urban growth, such as urban obesity, heavy loads of traffic, deteriorated inner city neighborhoods, and lack of public spaces (Nechtya & Walsh, 2004; Sudhira, Ramachandra, & Jagadish, 2004[1][2][3]). Urban sprawl is emerging from urban centers to peripheral areas, and an increase of urban built-up areas is usually considered as effects of sprawl (Barnes, Morgan, & Roberge, 2001; Fang, Lui, Yuan, & Zhang, 2007[4][5][6]). Quantization is the procedure of constraining something from a continuous set of values (such as the real numbers) to a relatively small discrete set (such as the integers) (QP, 2015[7]). It is necessary to indicate which parameters can be considered as indicators for sustainable development in urban sprawl. In this aspect, quantization is a process of taking these parameters into digitizing analysis and revealing how do these parameters affect the process of urban sprawl in China.

2. Data analysis

According to the definition of urban sprawl, it is actually a phenomenon that can be expressed and quantified using a series of special parameters. The simplest parameter of urban sprawl is the average density of urban built-up areas (Malpezzi and Guo, 2001[8]). Some scholars have taken three parameters for measuring and analyzing urban sprawl: residential density; neighborhood mix of homes, jobs, and services; and accessibility of the street network (Ewing et al., 2002[9]). For sustainable development, it is closely interrelated with (a) population growth in an urban area indicates the migration from rural areas and other regions and its degree can be measured by the percentage of urban residents; (b) urban environment characterized by limited open areas (green spaces) in specifically planned areas or places that
have been abandoned because of the higher value of real estate in urban areas (HLP, 2015[8]), so we need to gauge the
degree of urban environment through evaluating its urban green system; (c) residential living conditions that can be
shown by digital image and calculating living spaces (Wu, 2007[9]). Therefore, related index for urban sprawl and sus-
tainable development for the 15 top urban regions (urban areas, population, environmental conditions, urbanization rate,
living spaces, and so on) has been collected: Beijing, Shanghai, Guangzhou, Chongqing, Tianjin, Xi’an, Wuhan, Nan-
jing, Hangzhou, Shenyang, Shenzhen, Chengdu, Zhengzhou, Harbin, and Lanzhou. For the sake of accuracy and tim-
eliness, three specified point-in-times during 10 years (1999, 2004, and 2009) were chosen as a basic source for analysis
of this topic: one dependent variable is the rate of the increase for urbanized area (Y); Independent variables are Urban-
ization rate (X_1), Population density (X_2), Urban green coverage rate (X_3), Public greenbelt area per capita (X_4), and
The per-capita living area (X_5) (See Table 1, Table 2, and Table 3).

| The rate of urbanized area (%) | X_1 (%) | X_2 | X_3 (%) | X_4 (%) | X_5 |
|--------------------------------|---------|-----|---------|---------|-----|
| Beijing                        | 7.46    | 77.50 | 1,069   | 43.00   | 12.60 | 25.00 |
| Shanghai                       | 14.25   | 88.25 | 3,030   | 38.10   | 12.80 | 17.20 |
| Guangzhou                      | 11.35   | 63.40 | 2,276   | 45.00   | 10.20 | 29.70 |
| Chongqing                      | 1.74    | 51.59 | 382     | 38.00   | 10.00 | 29.70 |
| Tianjin                        | 7.21    | 75.11 | 861     | 38.50   | 8.00  | 29.89 |
| Xi’an                          | 8.56    | 68.80 | 756     | 40.33   | 7.80  | 28.40 |
| Wuhan                          | 5.59    | 64.75 | 984     | 37.46   | 9.22  | 30.88 |
| Nanjing                        | 11.89   | 64.57 | 1,150   | 46.50   | 13.60 | 22.70 |
| Hangzhou                       | 20.01   | 51.87 | 415     | 39.14   | 17.20 | 30.85 |
| Shenyang                       | 6.10    | 64.77 | 2133    | 36.00   | 10.11 | 14.80 |
| Shenzhen                       | 41.63   | 64.77 | 975     | 41.83   | 12.77 | 30.90 |
| Chengdu                        | 3.62    | 32.09 | 920     | 44.40   | 18.40 | 29.90 |
| Zhengzhou                      | 4.53    | 41.50 | 998     | 34.50   | 9.70  | 26.60 |
| Harbin                         | 0.62    | 48.10 | 187     | 32.00   | 8.20  | 20.82 |
| Lanzhou                        | 1.29    | 62.66 | 254     | 23.22   | 8.52  | 14.55 |

Source: The statistical bulletin of the economic and social development of China in 2010

| The rate of urbanized area (%) | X_1 (%) | X_2 | X_3 (%) | X_4 (%) | X_5 |
|--------------------------------|---------|-----|---------|---------|-----|
| Beijing                        | 4.58    | 73.50 | 708     | 41.91   | 9.98 | 19.09 |
| Shanghai                       | 10.90   | 81.20 | 2133    | 36.00   | 10.11| 14.80 |
| Guangzhou                      | 9.01    | 79.80 | 975     | 30.20   | 9.14 | 18.18 |
| Chongqing                      | 0.79    | 43.50 | 380     | 20.90   | 4.09 | 22.76 |
| Tianjin                        | 5.03    | 59.60 | 859     | 35.00   | 8.10 | 18.64 |
| Xi’an                          | 2.30    | 63.28 | 726     | 30.66   | 5.03 | 12.90 |
| Wuhan                          | 2.57    | 61.67 | 925     | 36.03   | 8.83 | 24.25 |
| Nanjing                        | 6.02    | 71.70 | 887     | 44.50   | 11.00| 21.61 |
| Hangzhou                       | 4.12    | 61.62 | 393     | 38.00   | 8.00 | 17.80 |
| Shenyang                       | 2.28    | 64.32 | 534     | 38.10   | 9.80 | 21.55 |
| Shenzhen                       | 28.16   | 100.00| 5000    | 45.00   | 16.00| 22.75 |
| Chengdu                        | 3.18    | 42.82 | 849     | 36.10   | 9.15 | 27.10 |
| Zhengzhou                      | 3.26    | 36.37 | 940     | 35.00   | 7.30 | 22.60 |
| Harbin                         | 0.57    | 48.07 | 180     | 32.10   | 6.48 | 15.94 |
| Lanzhou                        | 1.08    | 58.51 | 232     | 21.48   | 6.90 | 15.67 |

Source: The statistical bulletin of the economic and social development of China in 2005

Table 1. DATA IN 2009

Table 2. DATA IN 2004
Table 3. DATA IN 1999

| The rate of urbanized area (%) | X₁ (%) | X₂ | X₃ (%) | X₄ (%) | X₅ |
|-------------------------------|--------|----|--------|--------|----|
| Beijing                       | 3.38   | 77.50 | 766 | 35.30 | 8.20 | 15.44 |
| Shanghai                      | 8.84   | 73.84 | 2071 | 20.30 | 3.62 | 10.90 |
| Guangzhou                     | 3.83   | 61.31 | 907 | 29.34 | 7.40 | 12.21 |
| Chongqing                     | 0.36   | 20.67 | 372 | 20.13 | 2.37 | 9.51 |
| Tianjin                       | 4.53   | 57.12 | 886 | 24.50 | 5.40 | 13.80 |
| Xi’an                         | 1.60   | 40.94 | 689 | 36.40 | 6.76 | 9.01 |
| Wuhan                         | 2.33   | 58.71 | 320 | 27.54 | 7.94 | 8.50 |
| Nanjing                       | 3.05   | 53.41 | 815 | 41.00 | 8.58 | 9.68 |
| Hangzhou                      | 2.59   | 28.44 | 371 | 33.50 | 12.80 | 10.10 |
| Shenyang                      | 1.66   | 63.42 | 528 | 23.91 | 4.36 | 8.37 |
| Shenzhen                      | 15.36  | 100.00 | 3596 | 45.00 | 13.98 | 15.30 |
| Chengdu                       | 1.67   | 33.50 | 818 | 22.50 | 3.52 | 10.90 |
| Zhengzhou                     | 1.68   | 34.20 | 838 | 30.70 | 4.60 | 9.25 |
| Harbin                        | 0.19   | 45.10 | 183 | 39.54 | 4.08 | 8.60 |
| Lanzhou                       | 1.02   | 54.44 | 291 | 12.09 | 2.59 | 8.89 |

Source: The statistical bulletin of the economic and social development of China in 2000

In these urban regions, I focused on latitudinous studies. I mainly use linear regression analysis with the program SPSS (Statistical Program for Social Sciences). During the process of analysis, I separately used the fluctuation for independent variables (X₁, X₂, X₃, … and X₅) compared with the rate of the increase for urbanized area (Y) in three periods: from 1999 to 2004 and from 2004 to 2009. Undoubtedly, in two periods, from 1999 to 2004 and 2004 to 2009, urban built-up area continues to increase because of rapid urban development and great infrastructure construction.

With the increase of the urbanized area, independent variables are in general maintaining a rising trend. However, we should note the following:

1). From 2004 to 2009: in Guangzhou, Nanjing, Hangzhou, and Chengdu, Urbanization rate (X₁) shows negative increment; in Shenzhen, Population Density (X₂) shows negative increment; in Zhengzhou and Harbin, Urban green coverage rate (X₃) shows negative increment; in Tianjin, Public greenbelt area per capita (X₄) shows negative increment; in Lanzhou, The per-capita living area (X₅) shows negative increment; and in Shenzhen, Urbanization rate (X₁) and Urban green coverage rate (X₃) shows stabilizing.

2). From 1999 to 2004: in Beijing, Urbanization rate (X₁) shows negative increment; in Beijing, Tianjin, Harbin, and Lanzhou, Population Density (X₂) shows negative increment; in Xi’an and Harbin, Urban green coverage rate (X₃) shows negative increment; in Xi’an and Hangzhou, Public greenbelt area per capita (X₄) shows negative increment; and in Shenzhen, Urbanization rate (X₁) and Urban green coverage rate (X₃) shows stabilizing.

3). From 1999 to 2009: in Chengdu, Urbanization rate (X₁) shows negative increment; in Tianjin and Lanzhou, Population Density (X₂) shows negative increment; in Harbin, Urban green coverage rate (X₃) shows negative increment; in Beijing, Urbanization rate (X₁) shows stabilizing; and in Shenzhen, Urbanization rate (X₁) and Urban green coverage rate (X₃) shows stabilizing.

In sum, in Harbin, urban green coverage rate (X₃) shows negative increment with the increase of urbanized area for the three periods. Obviously, urban infrastructure, especially for greenbelt area and public green spaces, falls behind with rapid urban expansion in Harbin for the recent 10 years.

Data analysis from 1999 to 2004

Based on linear regression analysis with the program SPSS from 1999 to 2004 (See Table 4 and Eqs. 1): with the fluctuation of the rate of increase of urbanized area (Y), Urbanization rate (X₁), Population density (X₂), and Public greenbelt area per capita (X₄) are maintaining a rising trend and X₅ is at the positive peak, but Urban green coverage...
rate \((X_3)\) and The per-capita living area \((X_5)\) show negative increment. The independent variable of the most negative fluctuation is the per-capita living area \((X_5)\) and the most positive fluctuation is Public greenbelt area per capita \((X_4)\).

Why do the public greenbelt area per capita \((X_4)\) and the per-capita living area \((X_5)\) have totally contrary developing trends compared with the fluctuation of the rate of increase of the urbanized area \((Y)\)? Public greenbelt is a key part (including natural and artificial sectors) within the complicated urban ecosystem, and Public greenbelt area per capita is a significant indicator to evaluate living environmental quality and urban livability (Tüzin & Nijkamp, 2009\(^{[10]}\)). With the end of the housing provision system reform in 1999, real estate markets in big cities have been overheated and a lot of commercial housing is booming. To attract the attention of developers and enhance the price of prime land, city governments have made a big investment in urban infrastructure, including public greenbelt (parks, urban forest, and planted areas, and waterways and streets that can be used for recreation or public health benefit, or to help protect the natural landscape). Moreover, the purposes of greenbelt policy (improving public greenbelt area per capita) from city governments are: (a) mitigating social pressure from sprawl and (b) redeveloping inner-city areas to revitalize old urban centers (Lai & Ho, 2001\(^{[11]}\)). Therefore, from 1999 to 2004, Public greenbelt area per capita \((X_4)\) maintained the most positive fluctuation for the rate of the increase of urbanized area \((Y)\) in China. In the process of urban sprawl, due to some policy obstacles such as the Hukou system*, a large part of migration cannot really be urban residents. Simultaneously, original residents in traditional centers are forced to move out due to urban renewal and the population of central cities declines, but new urban areas cannot successfully attract original residents in traditional centers because of skyrocketing housing prices and expensive living costs. Consequently, urbanization is not a match with the speed of urban sprawl. In other words, in the process of urban sprawl, current urban regions cannot attract sufficient migrants to settle in towns and increase the concentration of population in both the inner cities and suburban areas. Because the increase of population follows the process of urban sprawl, the per-capita living area \((X_5)\) has a decreasing trend under the circumstance of rapid growth rate of the urbanized area.

| Coefficients\(^a\) from 1999 to 2009 | Unstandardized Coefficients | Standardized Coefficients |
|--------------------------------------|-----------------------------|----------------------------|
| Model                               | \(B\) | Std. Error | Beta | \(t\) | Sig. |
| (Constant)                           | .551 | 1.277 | .431 | .676 |
| 1999 to 2004                         | X1   | .127 | .058 | .420 | 2.180 | .057 |
|                                      | X2   | .008 | .001 | .980 | 6.407 | .000 |
|                                      | X3   | -.057 | .081 | -.121 | -.708 | .497 |
|                                      | X4   | .509 | .243 | .442 | 2.098 | .065 |
|                                      | X5   | -.203 | .106 | -.278 | -1.917 | .087 |
| (Constant)                           | 2.157 | 2.259 | \(t\) | .955 | .365 |
| 2004 to 2009                         | X1   | -.299 | .153 | -.534 | -1.949 | .083 |
|                                      | X2   | -.001 | .003 | -.117 | -.419 | .685 |
|                                      | X3   | -.317 | .217 | -.371 | -1.460 | .178 |
|                                      | X4   | -.019 | .431 | -.012 | -.044 | .966 |
|                                      | X5   | .627 | .253 | .613 | 2.478 | .035 |

\(a. \) Dependent Variable: \(\hat{Y}\)

\[\hat{Y} = 0.551 + 0.127X_1 + 0.008X_2 - 0.057X_3 + 0.509X_4 - 0.203X_5\] Eqs.1

Table 4. Coefficients\(^a\) from 1999 to 2009

Based on Table 4, the result shows P (Sig.) for \(X_1\): 0.057 \((X_1)\), 0.000 \((X_2)\), 0.497 \((X_3)\), 0.065 \((X_4)\), 0.087 \((X_5)\). Correlation is significant at the 0.05 level (2-tailed). The result is that Population density \((X_2)\) is the significant parameter for the rate of increasing of the urbanized area \((Y)\) and Urbanization rate \((X_1)\), Urban green coverage rate \((X_3)\), Pub-
lic greenbelt area per capita (X₄), and The per-capita living area (X₅) are all insignificant parameters from 1999 to 2004 compared to X₂. Why did only Population density (X₂) belong to the significant parameter for the rate of increase of the urbanized area (Y) from 1999 to 2004?

Generally, urbanization has two aspects: gaining product elements and creating trade market and concentration for a large population and emergence for residential housing and commercial buildings (Wang & Wang, 2008^{12}). From 1999 to 2004, China’s urbanization rate increased at 1.82% on average each year (from 30.89% to nearly 41.83%). Each year, millions of rural population flowed into cities in China since the 1980s and brought about a sharp growth in the urban population (Kwan, 2010^{13}). The result of Chinese urbanization is expansion of the urbanized areas. The unplanned expansion and fanatical pursuit of foreign-style cities led to the loss of their own regional characteristics of Chinese cities (Jiang, 2009^{14}). Later rapid urbanization directly leads to urban population growth. Urban land increased by 8% from 1999 to 2004 and the urban population grew by nearly 2%; in other words, a 1% increase of urban population will result in 4% increase for urbanized areas in this period, so it is not difficult to understand that Population density (X₂) is the only significant parameter for the rate of increase of the urbanized area (Y) from 1999 to 2004.

Through comprehensive analysis, Population density (X₂) has the closest correlation with the rate of increase of urbanized area (Y); Public greenbelt area per capita (X₄) has the futhest correlation with the rate of increase of urbanized area (Y); and Urbanization rate (X₁), Urban green coverage rate (X₅), Public greenbelt area per capita (X₄), and The per-capita living area (X₅) have a negative correlation with the increase of the rate of urbanized area (Y) from 1999 to 2004.

**Data analysis from 2004 to 2009**

With the increase of urbanized area, The per-capita living area (X₅) maintained a rising trend, but Urbanization rate (X₁), Population density (X₂), Urban green coverage rate (X₅), and Public greenbelt area per capita (X₄) maintained a declining trend from 2004 to 2009 and urban green coverage rate (X₅) was at the negative peak (the same as from 1999 to 2004; see Eqs. 2). The per-capita living area (X₅) was at the positive peak and urban green coverage rate (X₅) maintained a greatly declining trend from 2004 to 2009. Why did the urban green coverage rate (X₅) have a totally contrary developing trend compared with the increase of the urbanized area? The speed of new district sprawl is too fast and infrastructure construction falls, especially in the urban green and greenbelt. This will lead urban green coverage rate (X₅) of new urban areas to be even lower than traditional centers. Although the total urban green area is increased, new urban district area was far more than the increase of urban green area. Therefore, urban green coverage rate (X₅) of the whole urban region had a decreasing trend.

\[ \hat{Y} = 2.157 - 0.299X₁ - 0.001X₂ - 0.317X₃ - 0.019X₄ + 0.627X₅ \]  

Eqs. 2

However, the urbanization rate (X₁) also maintained a declining trend with the fluctuation of the rate of increase of the urbanized area (Y) from 2004 to 2009. Why? “Too many cities; too few people” leads directly to this unexpected result. China’s urbanization is highly localized, with less long-distance migration compared to other large countries, such as Brazil or the United States. The result of highly localized migration is diffuse urbanization, leaving most cities in China too small to exploit urban agglomeration economies efficiently, thereby limiting urban productivity gains and economic growth. Although a lot of cities have experienced heavy in-migration in the last few years (from 2004 to 2009), a strange trend has been emerging: too many new towns with too few residents (Henderson, 2009^{15}). So the ability to absorb migration is falling behind the pace of sprawl of urbanized areas for many Chinese cities in this period; in other words, although metropolitan areas are always extending and total living population is sharply increasing, the amount of migration transfer to local urban residents is limited due to the Hukou system in China. The urbanization rate is equal to the percentage of local urban residents to total residents and this percentage is declining with the growth of the rate of the urban built-up area (the rising of total residents is little faster than the increase of local urban residents) from 2004 to 2009.

Based on Table 4 in appendix, the result shows P (Sig.) for X₁: X₁: 0.083(X₁), 0.685 (X₂), 0.178 (X₃), 0.966 (X₄), 0.035 (X₅). Correlation is significant at the 0.05 level (2-tailed). The result is only the per-capita living area (X₅) is significant parameters for the rate of increase of urbanized area (Y) and Urbanization rate (X₁), Population density (X₂),
Urban green coverage rate \((X_3)\), and Public greenbelt area per capita \((X_4)\) are all insignificant parameters compared to the per-capita living area \((X_5)\) from 2004 to 2009.

From 2004 to 2009, a large amount of housing renewal and construction emerged, and the per-capita living area \((X_5)\) also skyrocketed \((PD, 2000^{16})\). Since 1999, the welfare-oriented public housing distribution system has become a thing of the past. Middle- or high-income residents can buy new housing in the commercial real estate market and poor people are expected to get only affordable housing with the aid of local government with subsidized prices \((Lin & Zhu, 2008^{17})\). Until 2005, most urban residents pursued bigger housing and a better living environment in inner-suburban areas according to their income conditions \((Environmental Change Institute, 2010^{18})\). For example, the housing conditions of urban residents in Tianjin has been greatly improved. In 2005, the per-capita living area for family households is more than 23 square meters, and it has increased nearly 20% compared with 2000 \((RGC, 2006^{19})\).

Through comprehensive analysis, the per-capita living area \((X_5)\) had close correlation with the rate of increase of urbanized area \((Y)\); Public greenbelt area per capita \((X_4)\) had the furthest correlation with the rate of increase of urbanized area \((Y)\), the same as from 1999 to 2004; and Urbanization rate \((X_1)\), Population density \((X_2)\), and Urban green coverage rate \((X_3)\) had a negative correlation with the fluctuation of the rate of increase of urbanized area \((Y)\) from 2004 to 2009.

3. Conclusion

Through urban sprawl, property developers can reap great profits from residential housing construction in new urban built-up areas due to high housing prices and commercial redeveloping projects in inner-city areas by urban renewal; however, local governments can make large profits from the conveyance of land-use rights and related taxes. Central and provincial governments have a share in “revenue from leasing land use rights,” and “charges on land leasing” are the main revenue for local governments \((Zhang, 2000^{20})\). Different government authorities have pursued different interests through their own regulations and policies, so conflicts are becoming sharp \((Ding, 2003^{21})\). Therefore, it is not difficult to understand why developers and government officials continue to engage in and promote sprawling development. Large investment from local government has been spent on development zones, transferring rural lands around cities into new urban lands, but lots of land in development zones have not achieved the anticipated use purposes or will remain vacant for several years \((Deng & Huang, 2004^{22})\). Urban renewal is based on property development and leads to changes to existing urban fabrics. Large urban redevelopment projects are driven by reconstruction of residential housing and transformation of land-use rights. The relocation of original residents has unavoidably brought about social conflicts between them and developers or local governments because of large commercial profits \((He, Li, & Wu, 2006^{23})\). Moreover, due to great profits from the conveyance of land use rights, illegal issues for land requirement cannot be totally avoided. So the central government should adjust local finance and tax systems to reduce revenues from land leasing for local governments and ensure that they put more land into the construction of low- and middle-income housing.

We find that causes of urban sprawl in China include the changing residential preferences of some residents willing to move out of the core, and overcrowded, deteriorated, and old-fashioned structures in central cities becoming targets for demolition in pursuing a new era of modernity, prosperity, and renaissance. In China, with the large scale of urban sprawl, traditional urban centers are still attractive and prosperous; the rich and old people prefer staying in downtown areas because of a better living environment and public services facilities, and most young couples and people who cannot afford the high prices have no choice but to move to suburban areas. With the large scale of urban renewal, dilapidated downtown areas have been renewed and are becoming the place of high land prices and rent. The original, mainly low-income group is replaced by the middle class and urban infrastructure facilities; this process has negative effects on the low-income group in both countries. In China, urban renewal has been mostly realized through transformation of urbanized villages in inner cities and around urban fringes, and updating urban infrastructure facilities as a part of urban sprawl.

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