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3 **A temporally cyclic growth model of urban spatial morphology in China:**
4 **evidence from Kunming Metropolis**
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10 **Abstract:**

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12 Rapid urbanization and complexity of political-economic transition in China has
13 brought about continuous and remarkable changes of urban morphology over the past
14 decades, which were driven by a mixture of spatial, social-economic and institutional
15 forces. Understanding such urban morphological evolution requires new mixed
16 evidences and holistic perspectives. In this paper, it is argued that two dominant types
17 of urban growth in China: low-density expansion and high-density infill might be
18 driven by different forces at different stages. To interpret the processes of urban
19 development, two easy-to-understand morphological indicators: expansion-induced
20 investment density index” (EID) and “infill-induced investment density index” (IID)
21 are defined to measure the investment density per unit of developed land and used to
22 compare the morphological changes between different phases in a long period by
23 integrating spatial and socio-economic data. The temporal variation of these indicators
24 suggests a cyclic growth model (CGM), which means the periodic switch between low
25 density expansion and high-density infill. Using Kunming metropolis as a case study,
26 this paper has confirmed that its urban morphological evolution from 1950-2014 was
27 periodically and reciprocally driven by a set of vis-à-vis dualistic dynamics, in which
28 low-density expansion is led by pro-growth infrastructure oriented public investment,
29 while the high-density infill is activated by collective and rational actions of
30 individual enterprises and their economic behaviors. It is concluded that the confirmed
31 CGM model, together with two morphological indicators, offers a new holistic
32 perspective and method to easily and integrally interpret urban morphological
33 evolution and accordingly has potential theoretical implications for reasonably
34 understanding the urbanisation in China.
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3 **Keywords:** Urban morphology; cyclic growth model; low-density expansion;
4 high-density infill; Kunming
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8 **1. Introduction**

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12 With the dazzling achievement of economic development, China has approached a
13 fast urbanization epoch and demonstrated a spectacular growth for three decades
14 (Barro, 2016).The built-up area of 652 Chinese cities increased by 39,628 km² from
15 12,474 in 1988 to 52,102 km² in 2015, which equals to 95.39% of the total territory
16 area of Netherlands (41,543 km²) (NBSC, 2015). Thereby, the case studies of Chinese
17 cities on pattern transition of urban growth offer a wonderful opportunity to
18 understand the hidden spatial and social processes behind the fast urban
19 morphological evolution.
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29 Urban morphology is the tangible aspects (e.g. the shape, organization or structure of
30 spatial entities) of social-economic forces (Whitehand, 1987). Although a city can be
31 viewed as a product of specifically social forces set in motion by capitalist relations of
32 production, it cannot be exclusively denied that city may be interpreted as a social
33 ecology, subject to natural forces inherent in the dynamics of population and space. In
34 the relevant literature of urban growth, morphological analysis involves both static
35 geometric shape or structure and dynamic pattern of urban entity, and the
36 morphological transition is often classified into three categories of form, namely,
37 edge-expansion/sprawl, outlying expansion and infill (Hoffhine et al., 2003; Sun et
38 al.,
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40 2013; Long et al.,2017). The static pattern analysis, dominated by landscape matrix, is
41 used to measure, monitor and compare spatial fragmentation caused by urban growth
42 (Hoffhine et al., 2003; Sun et al., 2013). By contrast, the dynamic pattern analysis is
43 utilized to understand and predict the patterns, processes and behavior of urban
44 growth (Cheng and Masser, 2004; Batty, 2007). Irwin and Bockstael (2007) revealed
45 that fragmentation rises and falls with distance and the point of maximum
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3 fragmentation shifted outward over time, after investigating the dynamics and spatial
4 fragmentation of land uses in a rapidly urbanizing area. This finding suggests that
5 there are some perceivable rules of spatial-temporal interaction, which derives the
6 spatial-temporal relationship in urban morphological shift. This has become the main
7 concern of this paper.
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14 Urban spatial transformation results from multiple overlapping socio-economic forces,
15 such as population growth, economic development, and infrastructure investments
16 (Cheng, 2003; Cheng and Masser, 2003a; 2003b). Brueckner (2000) highlighted that
17 growing population, rising incomes, and declining cost of commuting are three main
18 powerful factors to stimulate spatial expansion. Deng et al. (2008) confirmed
19 Brueckner's findings through an econometric analysis of the significant negative
20 impact of GDP on urban expansion in China. However, in contrast to the negative
21 externalities of economic forces, market forces are capable to derive land use changes
22 and enhance land-use efficiency internally. Du et al. (2014) analyzed the regulating
23 role of market mechanisms in the metropolitan land economy and articulated that land
24 price has exerted a significant influence on land-use conversion. Land price has
25 become an effective regulator in restraining urban/town expansion. The land market
26 in China has been criticized for long time as being less effective in managing land use
27 changes in both the exurban and urban redevelopment areas (Song et al., 2015). As
28 common goods, the use of land and land-use efficiency in the hand of individual
29 entrepreneur should adhere to the collective regulation of market (Deng et al., 2008;
30 Du et al., 2014). These regulations have demonstrated spatial and temporal variations.
31 For example, the urban expansion occurring in the western regions of China between
32 1950s-1990s, was driven and led more by market forces on demand side than by
33 government forces on supply side. However, the decentralization process and
34 tax-share reform initiated in middle 1990s have created their thirst for revenue,
35 thereby, local/city governments have practiced a Keynesian strategy of urban
36 development before 2000s or a more extreme strategy of land revenue through space
37 production after 2000s. The former means that the huge investment into infrastructure
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3 can entice manufacturing industries in suburb or commercial sectors in gentrified
4 downtown, then the business tax can be harvested indirectly. The latter indicates that
5 the infrastructure investment can attract real estate companies to buy land directly in
6 the newly developed suburb (He et al., 2014). Consequently, low-density urban
7 expansion is mainly driven by the state rather than market forces in the suburbs, while
8 high-density urban regeneration is dominantly driven by market force in downtown.
9 Apart from socio-economic forces, governments and their policies are more required
10 to respond to the pro-growth based urban sprawl (Lichtenberg and Ding, 2009). Local
11 governments at various levels take advantages of the dual land market system (Zhang,
12 2000; Li et al., 2015) to pursue high land revenue or as what Du et al. (2014) further
13 stated that land is not a simple factor of production but a strategic tool for promoting
14 urban government. The decentralization of labor and economic activities has been one
15 of the main driving forces of spatial expansion since 1980s (Deng, et al., 2008). Zhao
16 (2010) argued that urban expansion has been massively fueled by increasing local
17 government autonomy and fiscal responsibility. The negative effects of sprawling
18 development on transportation (e.g. enlarged commuting distance), reflect the
19 government's failure to manage growth in the ongoing transformation process.
20 Additionally, some growth oriented policies, such as favoring single-family housing
21 regulation that contributes to unrest sprawling in California (Quigley et al., 2004),
22 also have their considerable effects on urban expansion in the Chinese cases, e.g.
23 China's real estate markets nowadays cater for large floor-space housing (Jim and
24 Chen, 2007). Since urban growth, in particular inefficient sprawl is regarded as
25 negative externalities, the institutional antidotes are requested to cope with these
26 issues. In order to restrain inefficient urban expansion in the political-economic
27 hemispheres, it is imperative to internalize negative externalities of urban sprawl,
28 including some policies in practice, such as the gasoline taxes, improvement of mass
29 transit and pedestrian access in the inner city, zoning regulations, and land tax. The
30 policy of land bank was announced and implemented in China in later 1990s, based
31 on the western experience, to improve the land productiveness through state
32 intervention in land use decision-making (Lichtenberg and Ding, 2009). Furthermore,
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3 some property-led urban growth policies and practices have enhanced the intensity of
4 inner city development through large-scale regeneration since 1990s (Zhang, 2000).
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6 The impacts of these policies and practice, to some extent, demonstrate that
7 high-density expansion (Jiao, 2015), or even smart growth, may be driven by
8 exogenous policy intervention in long run indirectly, such as endogenous force of
9 economic activities.
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16 Consequently, amalgamating the exogenous force of institution and endogenous force
17 of economics and their spatial impacts into an integrated and dialectic framework of
18 analyzing urban morphological evolution, which has been illustrated by Figure 1,
19 might be an appropriate framework for understanding the interactions between
20 different forces driving urban development, which offers a different perspective for
21 interpreting urban morphology.
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29 [Insert Figure 1: The dually dialectic forces of urban growth]
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32 This paper aims to examine if the urban morphological evolution of Kunming
33 metropolis follows a cyclic growth model (CGM) driven by the dually dialectic forces.
34 A cycle of a dual phase of growth (Whitehand, 1987) is defined by low-density
35 expansion versus high-density infill, and the cycle is periodically and reciprocally
36 derived by a set of vis-à-vis dualistic dynamics resulting from the complicated
37 interactions between macro policies (e.g. pro-growth infrastructure investment) and
38 micro behavior (e.g. collective and individual enterprise / economic behavior).
39 Kunming in the Southwestern China is chosen as a case study because it has
40 experienced massive changes and shared similar spatial and economic processes with
41 the rest of Chinese cities. This paper is organized as follows. After this introduction,
42 section two describes the study area and its methodology including data collection and
43 morphological indicators. Section three presents the results of morphological analyses.
44 Section four tends to theorize the CGM model and reveal the dynamic mechanism of
45 urban morphological evolution. The paper ends with some conclusions and
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3 recommendation for future work in section five.
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7 **2. Study area and methodology**

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10 Theoretically, the urban morphological evolution is driven by the twist of bifurcated
11 and opposite but mutually compensated forces of external pattern shift and internal
12 dynamic fluctuation. Thereby, methodologically, the evolution can be detected by
13 pattern metric and social-economic and spatial indices jointly on one hand, and
14 embodied into the metrics of switching between expansion and infill on the other
15 hand. The analytical methods should be able to reflect both observable external
16 pattern shift and hidden efficiency of land use, and explore the pattern switches with
17 time. For example, some pattern metric indices including the traditional static
18 geometrical indexes - R index (Sun et al, 2013) and average trip distance (Muñiz and
19 Galindo, 2005), can help distinguish the categories of urban growth between suburban
20 expansion or sprawl, and “inner” city infill development. Some other socio-economic
21 indicators, e.g. investment per km², productivity of urban economic actives (GDP per
22 km²) and development intensity, can measure the internal dynamic fluctuation. In the
23 following sections, two new morphological indicators will be designed and explained
24 to achieve this purpose of integrating spatial pattern and socio-economic driving
25 forces.
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41 **2.1 Study area**

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45 Kunming is located in east-central Yunnan Province of which it is the capital. As the
46 third largest city in south-west China (after Chengdu and Chongqin), Kunming
47 administers six urban districts, four counties, three autonomous counties and one
48 county-level city (Figure 2), with a total area of 21,012 km² (Wu et al., 2015). It is
49 undergoing a transition from a socialist manufacturing center to a free market service
50 economy with a focus on tourism and bio-chemicals and flower production (Wu et al.,
51 2015). The effects of this shift, especially in the development of a commodity housing
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3 market, have only been seen relatively recently (Zhang, 2010).
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7 [Insert Figure 2. Location of the study area – Kunming Municipality.]
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10 Kunming is a regional central city in South-east Asia, which dates back to Tuodong
11 city that existed about 1200 years ago, and its morphology has undertaken massive
12 changes in the past 12 centuries. Before the Second Sino-Japanese War (1937-1945),
13 Kunming was a tessellated city. However, its population, economy and urban built-up
14 area increased quickly during the war due to the migration of numerous factories,
15 departments and schools into Kunming from coastland and inland, and this has
16 become the fastest developing period in the modern history of Kunming. After 1949,
17 Kunming was developed into a megalopolis, and the downtown area expanded from
18 7.8 km² in 1949 to 98 km² in 1995, while the population increased from 270,000 in
19 1949 to 1,260,000 in 1995 (KMG,1999). In the 21th century, the urban area has
20 expanded from 136.5 km² in 2000 to 249 km² in 2007, while the urban permanent
21 population has grown from 1,517,000 in 2000 to 1,632,000 in 2007 accordingly
22 (KMG,1999; 2003; KBS, 2008). Kunming has witnessed the rapid urbanization,
23 including urban sprawl (Wu et al, 2014; Wu and Waley, 2017) and residential
24 segregation (Wu et.al., 2017) in the past four decades.
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40 **2.2 Data collection and participatory mapping**

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43 The social and economic data, including the public investment, real estate investment,
44 urban built-up area and building floor area, were all collected from multiple sources
45 of publicly published documents, e.g. KMG (1999, 2003), KBS (2005, 2006, 2007,
46 2008, 2009 and 2010), KBSM (2014) and SBYP (2014). The GIS data was digitized
47 into ArcGIS 10.4 from the following sources: (i) the historical maps and earlier
48 archives from local chronicles, particularly in the period from 1909-1949; (ii) master
49 planning maps in these periods: 1943, 1953, 1957, 1959, 1962, 1982, 1987, 1995;
50 2002, 2006, and 2008 respectively. Spatial data sets are processed and integrated to
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3 map urban morphological evolution from 1909-2006 (Figure 3). Combining with
4 statistical data of investments, two indicators are calculated for the entire study period,
5 which will be explained in detail in the next sub-section.
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8 Due to limited availability of spatial and temporal data for the urban growth occurring
9 before 1980s, Participatory Mapping (PM) method has been extensively applied in
10 this study to capture local spatial and situated knowledge related to evolution of urban
11 morphology (Mapedza et al., 2003). PM, as a qualitative GIS approach, aims to
12 socially produce or construct spatial knowledge through public participation in
13 mapping. In this study, seven senior urban planners were invited into workshops to
14 help recognize the development type and process of those representative building
15 blocks (images 1-7 in Appendix 1), which indicate the urban development phases in
16 1950s, 1990s, 2000s and 2010s respectively, identified from Google Map and Google
17 Earth.
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29 **2.3 Morphological indicators**

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32 Comparing to traditional geometric shape analysis, Hoffhine et al. (2003) developed a
33 quantitative method to characterize three urban growth categories: infilling, edge
34 expansion, and outlying. Sun et al. (2013) further defined a metric R to measure the
35 above-mentioned three types of urban growth into equation 1:
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$$41 \quad R = l_c / l \quad (1)$$

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45 Where l_c is the length of commonly shared edge between a newly developed urban
46 patch and an existing urban patch and l is the perimeter of the newly developed urban
47 patch. The value of R ranges from 0 to 1. For the infilling type, $R > 0.5$ and $R < 0.5$
48 for edge-expansion. As outlying growth is the newly developed urban area without
49 spatial connection to the existing urban area, $R = 0$. In our study, it is preferred to
50 abstract the urban growth as two categories, namely infilling vs. expansion.
51 Consequently, 0.5 is selected as a threshold value for distinguishing them. However,
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3 this indicator R , though it is easy to be calculated and interpreted from the urban
4 morphology map (Figure 2), has less power to reveal the pattern of regeneration and
5 reuse the dilapidated land in the existent urban built-up areas.
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10 In economics, investment has been often regarded as the internal forces of stimulating
11 cyclic growth (Krawiec and Szydłowski, 2017). In the previous studies of urban
12 growth, density-based indicators have been extensively used to explain the patterns
13 and driving forces of spatial development, such as population density and
14 employment density. However, these indicators can hardly explain the economic
15 behavior behind the spatial development. Economically, the investment intensity of
16 low-density expansion determines the scale of built-up area converted from non-urban
17 to urban uses, including transport infrastructure. The investment intensity of
18 high-density infill development affects the magnitude and quality (e.g. total floor area)
19 of high-rise buildings due to the profit-oriented real-estate development. Thereby,
20 investment density, which links investment intensity with spatial development, can
21 help better interpret the economic behavior behind the urban spatial development. Du
22 et al. (2016) have defined an index of investment density as the division of
23 accumulative investment by the complete developed land area in their study on
24 impacts of land pricing on land use efficiency in Beijing. In this paper, in order to
25 remedy a defect of the spatial indicator R , and simplify the dynamics of
26 morphological evolution, two indicators: “expansion-induced investment density
27 index” (EID) and “infill-induced investment density index” (IID) are defined to
28 reflect the two distinct spatial processes: low-density expansion and high-density infill
29 respectively (equations 2 and 3):
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$$EID_i = PI_i / BA_i \quad (2)$$

$$IID_i = RI_i / BF_i \quad (3)$$

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56 EID and IID are used to measure the investment intensity per unit of developed land
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3 in the urban fringe or city centre, which indicate the intensity or opportunity of
4 triggering low-density expansion and inducing high-density infill respectively.
5 Mathematically, *EID* is calculated as the division of the intensity of public investment
6 (PI_i) by the total built-up area of a city (BA_i) in year i , where the public investment (in
7 China, the public investment has been nearly equal to the investment on infrastructure
8 since 1949). *IID* is measured as the division of the intensity of real estate investment
9 (RI_i) by the total building floor area of a city (BF_i) in year i . The two indicators
10 designed in this paper enable us to better understand the complicated urban growth
11 process as they combine both spatial and economic elements into one formula.
12 To remove the scaling effect, both indicators are normalized by equation 4 in order to
13 compare and reveal their dynamic relationship:
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$$23 \quad X^* = (x - \mu) / \sigma \quad (4)$$

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27 Where μ denotes the mean value of the whole variable and σ represents its standard
28 deviation.
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31 32 **3. Results**

33 34 35 **3.1 Evolution of urban morphology**

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40 Though Kunming had been the political centre of Yunnan province, it was not set as a
41 municipal city until 1928. Over the past one century 1900–2010, there have been
42 many political, socio-economic historical events at national and local levels having
43 massively affected its administrative division (Wu et al., 2015; Wu and Waley, 2017)
44 and development of Kunming's urban morphology (Figure 3). For example, the
45 suburban district outside the inner beltway of Kunming municipality was Kunming
46 County from 1950 to 1956. After 1956, the Kunming County was merged into the
47 Kunming municipality and it was further divided into two suburban districts.
48 Although Kunming has 1100 years history, it started to experience a significantly
49 morphological evolution stimulated by its industrialization since middle 1900s
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3 (Figure 3). Based on the morphological evolution from 1909 -2006 in Figure 3,
4 together with the qualitative analysis from interviews with seven senior urban
5 planners, a conceptual model is presented into Figure 4, which divides the urban
6 development into five phases. This model helps us form a hypothesis that the
7 morphological evolution in Kunming metropolis is dominated by a periodic cycle of
8 urban expansion and infill development. However it is unclear which forces
9 contribute to the pattern switch. In the following sub-sections, some quantitative
10 evidences will be provided to confirm the hypothesis and interpret the cycle model.
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20 [Insert Figure 3. The morphological evolution of Kunming 1909 – 2006]
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23 [Insert Figure 4. The five phases of urban growth of Kunming Metropolis from 1909
24 to 2014]
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29 **3.2 Temporal variation of morphological indicators**

30 Combining the spatial and economic data processed, three morphological indicators R,
31 EID and IID (equations 1-3) were calculated for the Kunming metropolis throughout
32 the 14 periods ranging from 1950-2008 (Table 1), which help us test if the spatial
33 patterns have matched with the morphological indicators. Apart from two short
34 periods (1955-1962 and 2002-2003), which might be affected by the limited data
35 quality and special events (e.g. Great Leap Famine see (Gráda, 2013)), the rest
36 periods all demonstrate the appropriate match between both. It means the two newly
37 created indicators are able to link the spatial pattern of urban growth with the
38 socio-economic forces behind it. To analyze the forces for which type of urban
39 growth, the temporal trend of EID and IID values measured for the period from 1950
40 to 2014 is displayed as a graph in Figure 5, from which the morphological evolution
41 of Kunming Metropolis can be divided into four stages, namely 1950-1978,
42 1979-1989, 1990-2003 and after 2003 respectively (Figure 5). The dual forces and
43 their interactions behind the temporal variation will be explained in the next sections.
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3 [Insert Table 1. The cyclic evolution of urban morphology in Kunming]
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7 [Insert Figure 5. The temporal variations of two indicators (EID and IID) in Kunming
8 since 1950]
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11 12 **3. 3 State-dominant stage in planning economy** 13

14 During this period 1950-1978, Kunming went through a few morphological
15 fluctuation sub-stages or periods (Figure 5, Appendix 1). Over the past 28 years from
16 1950 to 1978, the annual growth rate of public infrastructure investment intensity had
17 increased only by 20.27%, but the built-up area tardily increased by 6.55 times
18 (KMG,1999).
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23 In the early period of the First Five-Year Plan (1953-1957), the increasing public
24 investment concentrated in inner city had stimulated a rapid high-density infill
25 development, which was conducted by filling in the empty land between the city core
26 and nearby enclaves, such as isolated towns or villages. At the stage of restrictive
27 growth between 1950 to 1955, the R index value is 0.51 (>0.5) (Table 1),
28 demonstrating an infilling growth pattern. This pattern was determined by an
29 economic recovery from the civil war (1945-1949) and slow economic development
30 from 1949 to 1955. The image 3 in Appendix and Figure 3 is a representative urban
31 growth at this stage. As interpreted by several senior planners, this area results from
32 the low-density urban expansion occurring around the inner city during 1950-1955
33 before the Great Leap Famine (Gráda, 2013).
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43 From 1963-1977, Kunming was trapped in the long lag period as what other
44 cities in China experienced as well (Figure 5). However, the public investment
45 activities reinforced by the central government under the strong planned economy
46 system, had led an unstable but fluctuated central-state led low-density expansion and
47 local-state led high-density infill development. Among them, low-density expansion
48 characterized by leap-frog development of new industrialized towns and isolated
49 industrial complex in the follow-up four Five-Year Plans periods (1958–1962;
50 1966–1970; 1971–1975 and 1976–1980) (Naughton, 1996). The morphology of
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3 Kunming was gradually transformed from a compact core to a constellation shape. At
4 this stage, the R index values in the periods of 1955-1962 and 1962-1978 are 0.32 and
5 0.24 (<0.5) respectively (Table 1), indicating a tardily urban expansion. For example,
6 the rapid extension of transport infrastructure from 1953-1957 facilitated the gradual
7 transformation of the brim of built-up area to rosary industry corridor with *Shiba* in
8 the east, *Ciba* in the northeast, *Puji* in the northwest and *Majie* in the west (Figure 3).
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16 **3. 4 Transition stage: from planning economy to market**

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18 Over the whole period of 12 years (1978-1990), Kunming had experienced a full
19 morphological fluctuation period (Figure 5) with an annual growth rate of public
20 infrastructure investment intensity of 11.28%, but the growth of built-up area only by
21 1.34 times from 1978 to 1989 (Table 1):
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25 At the market-led high-density infill development sub-stage (1978-1985), the R
26 index values between 1977-1978 and 1979-1985 are 0.57 and 0.62 (>0.5) respectively
27 (Table 1), which demonstrate an accelerated and strong high-density infill
28 development under the urban economic reform (Naughton, 1996). In fact, Kunming
29 had developed a twin-core structure (e.g. northern area and inner city) internally and
30 forged a relatively compact form different from previous constellation expansion
31 externally (Figure 3). The annual public investment intensity during 1979-1985) was
32 9.46 million Yuan RMB per km², increased by 4.07 million Yuan RMB per km²,
33 compared to the annual growth rate of 17.06% in the previous period (1977-1978).
34 Then, at the second sub-stage (1985-1990), the R index value is 0.31 (Table 1), and
35 the IID is lower than the EID (Figure 5). It demonstrates that market-led high-density
36 infill development gradually became a counter-balance against state-dominant force in
37 planning economy.
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51 **3.5 State-led v.s. market-led stage of urban growth**

52 After the transition stage, Kunming has demonstrated a tendency of balancing
53 market-led and state-led urban growth models in the following two periods since 1990
54 (Figure. 5):
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3 First, in the first period from 1990 to 2002, a continuous low-density expansion
4 was mixed by a strong high-density infill development. This mixture is partly
5 reflected by the change of Average Investment Intensity (*AI*), which has steadily
6 increased from 17.69 million Yuan RMB per km² during 1985-1989 to 124.13 million
7 Yuan RMB per km² during 1999-2002 (Table 1). Thus, the EID curve was slightly
8 lower than the IID curve during this period, but both curves had maintained the
9 increasing trend until 2010 (Figure 5). Nevertheless, a part of these figures and index
10 values seem to conflict with our hypothesis that both IID and EID indices and their
11 morphological pattern should dialectically oppose each other (Figure 4). It is clear
12 that the morphological evolution of Kunming was twisted by two giant events (Mills
13 and Rosentraub, 2013), namely, the newly opened housing market initiated from
14 mid-1990s and the EXPO99. Certainly, the newly opened housing market caused the
15 first wave of high-density market led urban expansion through the gradual
16 high-density infill development (Zhang, 2002), which had removed the effects of low
17 density expansion of state-driven pro-growth development in the northern suburb
18 (image 4 in Appendix 1). While the latter then neutralized the high density infill
19 development under the housing market, with a large number of public investment on
20 infrastructure for EXPO99.
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38 As a matter of fact, due to rapid expansion for hosting EXPO 99, a market-led
39 high-density infill development has been detected by the IID or EID index (Figure 5
40 and image 4 in Appendix 1). During the period from 1997 to 1999, the *AI* value of
41 Kunming was 106.54 million Yuan RMB per km², with an annual growth rate of
42 19.28% (Table 1). The investment was mainly focused on large-scale inner city
43 renewal, such as infrastructure, real estate, and key construction projects¹ (Deng et al.,
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51 ¹ As a remnant of former planned economy, the central government has been
52 financially supporting these key projects endorsed by National Development and
53 Reform Commission of China since the economic reform in 1978, the rest of projects
54 have to be fuelled by local governments through all kinds of fund-raising.
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3 2014). However, in contrast to the high-density infill development, the pattern metric
4 index R values of 0.51 and 0.42 corresponding to the periods of 1997-2002 and
5 2002-2003 respectively (Table 1), reflected a high-frequency morphological
6 fluctuation of lower density expansion and high-density infill development. It is clear
7 that such a high-frequency morphological fluctuation and similar tendency of both
8 curves (IID and EID) reflect a paradoxical urban growth path experienced in
9 Kunming. On one side, its inner city practiced a high density and large-scale infilling
10 urban regeneration, by spending up a huge amount of local revenue between later
11 1990s and early 2000s (also see image 3 in Appendix 1). Unfortunately, on the other
12 side, because of the framework of political-economic decentralization, the municipal
13 government has to pay the bill of regeneration alone after tax share reform (Zhang,
14 2000). Hence, local government had to generate its revenues from land market, selling
15 a huge quantity of land through promoting urban expansion in suburb to balance the
16 budget. In fact, the annual newly increased urban land from farm-land reached 36.9
17 km² in 2002, much higher than the average increase of 12.44 km² during the period
18 from 1990 to 2014. Therefore, a hybrid urban growth pattern was confirmed not only
19 by a gradual switch from IID-led regeneration in the inner city (from 1997 to 2002) to
20 state-driven urban expansion EID (e.g. image 1 in Appendix 1), for increasing land
21 revenue (from 2003-2007), but also by infill development in the urban fringe (e.g.
22 image 2 in Appendix 1). All these have demonstrated a similar but slight increasing
23 tendency of both IID and EID curves since 2002 (Figure 5).

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Second, Kunming has demonstrated a multiple nuclei and hybrid urban growth
since 2003 (Fig. 5 and 3). Due to the frequent and sophisticated intervention of local
government in land market, this period (2003-2014) has witnessed a more clear
morphological fluctuation stages, in which not only the R index, but also IID or EID
index did clearly refer to a high-density or low-density model simply (Table 1 and
Figure 5). Particularly, the urban growth after 2007 clearly shows dialectic
fluctuations between a strong state-driven lower density expansion from 2007 to 2012,
and a counterattack of market-led high-density infill development since 2012.

The planning of Chenggong New Kunming around early 2000s has led to a

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3 fiercely state-driven low-density expansion from 2007 to 2012. Such expansion
4 absolutely differs to the morphological evolution in the previous period of hybrid
5 urban growth in which both high-density infill development and low-density
6 expansion have coexisted at same stage (Figure 4 and images 7 and 5 in Appendix 1).
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8 As a matter of fact, Kunming municipality invested a huge number of capital resource
9 on infrastructure for the project of new Kunming district during the period from 2007
10 to 2011. The investment has amounted to 28.84% of the newly added built-up area
11 (311 km²) and 45.38% of the total infrastructure investment from 1990-2014 that is
12 141.3 billion Yuan RMB (KMG, 1999; KBS, 2008; KBSM, 2014). However, the
13 residents of old Kunming are very much concerned about the increasing traffic cost
14 and poor accessibility in the newly developed New Kunming, a large-scale empty
15 buildings called “ghost city” has appeared (Yu, 2011; Chen et.al. 2015). Accordingly,
16 after nearly five years state-driven urban expansion, the unsustainable low-density
17 expansion has ended up in around 2012. Kunming has headed to a high-density infill
18 development stage since then. For instance, the public infrastructure investment
19 dropped to 4.71 billion Yuan RMB, only amounted to 33.34% of that in the previous
20 stage (1997-2007) (KMG, 1999; KBSM, 2014). At this stage, local government
21 retreated back from the front desk, however, it not only allured real estate industries to
22 replace them, but also ordered the sub-agencies of local government to move in, then
23 forced high density infill urban growth to boom involuntarily, which cause the
24 phenomena of “ghost city” more seriously (Chen et al., 2015). Consequently, the IID
25 curve has exceeded the EID since 2011 (Figure 5).
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45 **4. Discussion: a cyclic growth model**

46 The above-mentioned results clearly reveal that the complicated urban growth and its
47 morphological evolution may follow a cyclic and periodic growth model, as
48 illustrated in Figure 6).
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54 [Insert Figure 6. A cyclic growth model of urban morphological evolution]
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3 Batty (2007) contended that urban morphological evolution, as a complex system,
4 should be understood or abstracted as a dynamic process of aggregating somewhat
5 simpler systems. This thought has been successfully embodied into the simulation
6 models of cellular automaton (CA) or multi-agent system (Batty, 2007; Cheng and
7 Masser, 2004). Nevertheless, our results suggests that the simple systems are refined
8 or abstracted as two basic but twisted lines of urban growth: low-density expansion
9 and high-density infill development, based on the rational action theory of individual
10 and group economic behaviors (Ostrom, 2010). This follows Hegel's dialectics
11 thought on the simple systems and the urban morphological evolution does follow a
12 reductionable process (Gallagher et al., 1999). In the cyclic growth model, the
13 occurrence of specific urban growth, either EID or IID, is dependent on the
14 dominance of investment source and type:
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25 (1) Expansion dominance: the increasing infrastructure investment and capital
26 facilitates the massive flow of land supply into market under the pro-growth land
27 policy tools of China local governments (Deng et al., 2008; Du et al., 2014), which
28 results in the decline of land price accordingly. Thereby, this will create opportunity
29 for individuals, enterprises or agencies to make profits from cheap land for their social
30 production or consumption, e.g. building and buying spacious housing (Jim and Chen,
31 2007; Quigley et al., 2004) or factories in rapid low-density suburbanization.
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38 (2) Infill dominance: the retard or decrease of public investment has reduced the flow
39 of capitals into the land market of peripheral area, and then causes a high-density
40 landscape instead. This would relatively increase the land price or investing cost in
41 the urban fringe and make the sites in there less attractive for real estate investment.
42 Comparatively, the previously inefficiently utilized land or empty land in inner city
43 would become more competitive. Consequently, the return of more economic
44 activities or commercial investment to the inner city in small plots of regeneration
45 will then fill the "the disparity between potential ground rent and the actual rent
46 capitalized under the present land use" (Smith, 1979: 545).
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54 Given the alternate dual phases in urban growth, the spatio-temporal substitution
55 process between the urban expansion and infill development has formed a complete
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3 cycle of urban morphology as shown in Figure 6. The logic behind the process is that
4 cities sprawl restlessly for the benefits of tapping into existing infrastructure
5 competing with the disadvantages of high land cost in built-up areas (Chen, et al.,
6 2015). Thus, following the process of diffusion-limited aggregation, cities incline to
7 grow by adhering new buildings or zones along their fringe and the existing
8 development areas, as the developed infrastructure is attractive for new development.
9 This model implies that urban growth was essentially a sort of internal
10 social-economic and political-economic movements, and external spatial movements,
11 which were functioned by pairs of dual forces, mainly including global/regional
12 capital investment and flows, economic growth, population growth, industrial policy
13 alteration, planning intervention in urban functions, and urban industrial restructuring.

14 Also, the temporal phases of urban spatial growth and its internal
15 social-economic or political-economic dynamic conversion as shown in Figures 4-6
16 demonstrate characteristics of reductionable periodicity. During the contradictive and
17 dialectic interaction of urban land demand and supply, undoubtedly, the temporal
18 changes or processes of the public investment and its substitution effect (Marshall,
19 2004) determine the spatial and temporal patterns of urban land use (Figure 1). The
20 social production rate, economic fluctuation and land cost follow a simple linear trend
21 in every cycle of urban growth. As the public investment and its consequent
22 substitution effect have disturbed the demand rhythm of land for the urban social
23 economic activities, the urban morphological pattern demonstrates a nonlinear
24 fluctuation trend, which are affected by two alternate sub-processes, e.g. state driven
25 urban expansion or low-density expansion vs. market-led high-density infill
26 development (Figure 1):

27 In the periods of low-density expansion, with its grounding in Keynesian and
28 Franklin Roosevelt's New Deal's state interventionist approach (Davidson, 2011), the
29 most substantial intervention into urban social economic activities of state-led market
30 economy is increasing the public investment as it then motivates local businesses. It
31 enables to stimulate the public consumption and impulse the benign speed and scale
32 of the capital reproduction circling process. In such political and economic

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3 circumstances, large-scale public investment gives rise to the low-density and
4 high-speed urban expansion or urban sprawl definitely (Xiao et al., 2006).
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7 Whereas economic activities operate under market principles in a negotiated
8 market circumstance, the equilibrium between minimal input and maximum outcome
9 has become an inevitable choice for rational enterprisers. Hence, the evolution of
10 urban morphology can also be described as the macroscopic outcomes and
11 consequences of microscopic rational activities in urban regions. With such a rational
12 choice, the governmental public investment enables to certainly reduce the costs of
13 land utilization and urban infrastructure development, engendering the substitution
14 effect in market circumstance. For instance, during the two-span stages: later 1980
15 and around later 1990s, it was reasonably observed that concrete social economic
16 activities have chosen the traditional Smithianism production paradigm, meaning the
17 substitution of expensive investment by largest-scale cheap land. Finally, the
18 macroscopic and collective outcomes of microscopic and individual rational activities
19 within each enterprise, namely urban low-density expansion, becomes the classic
20 patterns of urban morphological evolution in state-led urban pro-growth and by state
21 interventionist approach (Davidson, 2011).
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34 In the periods of high-density infill development, it reflects the logical pursuit of
35 enterprisers. When the public investment in land market decreases, land price will
36 increase because the land supply tension and the cost of converting land into
37 productive activity of each enterprise begins to rebound accordingly. Thus, the
38 rational choice of enterprisers definitely enables to raise the land use intensity by
39 replacing the former low-density expansion model, which will cut down the costs of
40 land supply and transportation, and other expenditures associated with productive
41 activities. This trade-off drives the rational social economic activities to be allocated
42 based on a compact development model in inner city with two objectives. The first
43 objective is to reduce the comparatively expensive land expenditure using other
44 fungible factors or methods, for example, enhancing land use efficiency by increasing
45 floor area ratio, reducing the land cost of unit production, or using other endogenous
46 growth to minimize production inputs (Marshall, 2004). The second objective is to
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3 reduce the traffic and trade costs by being located in the sites with good transport
4 access and further cut down the expenditure of urban development in inner city.
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6 Consequently, as the intensity of public investment, gradually decreases, the land use
7 efficiency (or rather the investment intensity) is improved significantly, and the urban
8 morphology evolves into the infill development stage.
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14 **5. Conclusions**

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18 In general, the macroscopic evolution of urban morphology has its own inherent laws
19 and external mechanism. The case of Kunming confirms the CGM model—a cycle of
20 dual phases of urban development: low-density expansion versus high-density infill
21 development. This is the first time to interpret the urban morphological evolution
22 from a cyclic growth perspective, although economic cyclic growth theory has existed
23 for a long time and been applied for many urban processes (Eng-Larsson, et al., 2012).
24 These dialectically morphological shifts are periodically and reciprocally derived by a
25 set of vis-à-vis dualistic dynamics, in which low-density expansion is led by
26 pro-growth infrastructure oriented state investment, while the high-density infill
27 development is activated by collective and rational actions of individual enterprises
28 and their economic behaviors. This shift of urban morphological pattern in a long
29 period would help us interpret about land use changes and its regulation in more
30 details, and assist us in future planning.
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41 First, the CGM model of Kunming suggests the following points. The dialectic
42 evolution of urban spatial morphology (i.e. external expansion vs. internal infilling)
43 can be decomposed into a set of dual urban policies, e.g. Smithian pro-growth urban
44 policies for exogenous growth against property-led strategies for endogenous urban
45 growth. Thus, local government can propose different urban policies or strategies to
46 shape the varied morphology in the CGM model. The CGM model implies that a
47 particular pattern and its evolutionary tendency reflect the outcomes from the
48 interactions with various economic activities. Thus, urban planning organizations can
49 apply different planning tools to echo these different economic policies. For instance,
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3 the restraints in external intervening circumstance, e.g. tight land supply policies or
4 restricted land use policies (e.g. green belt and habitat reserve in the urban fringe),
5 will probably lead to the convergence of land use in intensity and efficiency, which
6 will not only echo property-led strategies for endogenous growth, but promote
7 sustainable development as well. In fact, it has been proved by some relevant
8 planning practices, such as the green belt in London Planning and growth boundary in
9 Smart Growth of US (Chapin, 2012). Local government might adjust the trajectory of
10 urban morphological evolution with a bundle of planning tools according to the
11 MCCG model (Zhang, 2000; Lichtenberg and Ding, 2009; He et al., 2014; Zhao,
12 2010). In the Kunming case, the high frequency of fluctuation between HDI or LDE
13 curves at the stage of 1997-2007, reflected that the tax-share policy transition
14 distorted the path of urban morphological evolution (Figure 5). After the tax share
15 reform in 1994, city/local government had to generate revenue for running
16 development projects, or funding public consumptions (e.g. schools and hospitals).
17 Therefore, in order to create sufficient revenue to regenerate the inner city, municipal
18 governments had to demolish and replace a large number of villages in suburb, then
19 triggered pro-growth urban expansion. At last, the infill development in inner city and
20 spatial expansion in suburb occurred simultaneously, but the expansion was
21 conducted by the financial needs of infill development.
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38 Second, the CGM model enables us to further understand the nature of urban
39 growth. As an instructional model of explaining urban growth, compared to
40 traditional demographical model and complex system dynamics model, on one hand,
41 the CGM model further reveals the nature of urban growth with a dialectic simple
42 systems philosophy and possesses a nature of self-convergence, e.g. urban growth is
43 fueled by social-economically exogenous force and institutionally endogenous force.
44 As such, the morphology evolves with a temporal series of switches between spatial
45 expansion and infill development. On the other hand, in contrast to traditional growth
46 model, it needs only fewer variables, reflecting local dimension automatically other
47 than global one.
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56 At last, the CGM model also demonstrates some implications of different index
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3 for analysis of urban growth. Since urban growth is a complex spatial-economic
4 process other than a simple process of urban land expansion or land uses conversion,
5 traditional geometry based indexes cannot fully reveal such complexities of urban
6 growth. For instance, the metric pattern R index only reflects that urban growth of
7 Kunming in the past century was dominated by spatial expansion (either edge
8 expansion or outlying growth). Because these indices overlook not only the land use
9 intensity change (e.g. all kinds of urban regeneration and reuse of dilapidated factories,
10 residential zones or public facilities) but also the development of unused land in the
11 built up area. Other social-economic indices, such as EID and IID in the CGM,
12 should be redefined to allow the index R to reveal some of missed infill movements.
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21 Kunming as a mega city in transition has been developing very fast recently. But
22 with mixed forces, its urban growth in the future should be smart sufficiently by
23 considering various social and environmental impacts. The analytical methodology in
24 this paper has left much space for further improvement due to data limitation.
25 Methodologically, it is imperative to develop a variety of development scenarios in
26 response to a wide range of investment sources and local policies, based on the
27 theoretical framework proposed in this paper and using other systematic models (e.g.
28 system dynamics and geo-simulation). At a micro scale, it is worth exploring the
29 bottom-up processes of land development under the mixed forces from state, local
30 municipality and real estate market using agent-based modelling methods if a wealth
31 of urban big data can be available to support the tasks. Theoretically, comparative
32 studies with other mega cities in the eastern and central China are urgently needed in
33 order to examine if the cyclic growth model represents a universal process across
34 China.
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47 However, the complexity and uncertainty of urban systems may weaken the
48 CGM model and make it uncertain on other scales of time and space. The following
49 areas need further exploration in the future. For instance, CGM is still beyond reach
50 of inner city regeneration or redevelopment, which in fact enforces the tendency of
51 infilling actives, unfortunately, neither IID and EID indices, nor traditional spatial
52 pattern index, could explain such geographical phenomena. There are some
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3 limitations in data sets as well although these data have validated the CGM model to
4 some extent. With higher-resolution imagery data for the entire study period in the
5 future, the geometric metrics of urban morphology can be analyzed in more details.
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Table 1. The cyclic evolution of urban morphology in Kunming

	Stage	AII	R	EID	IID	Match	
	<i>1950-1955</i>	1.67	0.51		√	Yes	
I	<i>1955-1962</i>	4.59	0.32	√	√	Vague	
	<i>1962-1977</i>	2.92	0.24	√		Yes	
	<i>1977-1978</i>	5.39	0.57		√	Yes	
	<i>1979-1985</i>	9.46	0.62		√	Yes	
II	<i>1985-1989</i>	17.69	0.31	√		Yes	
	<i>1990-1993</i>	35.31	0.18	√		Yes	
III	<i>1993-1995</i>	77.40	0.30	√		Yes	
	A	<i>1995-1997</i>	109.00	0.72		√	Yes
		<i>1997-1999</i>	106.54	0.51		√	Yes
	<i>1999-2002</i>	124.13	0.50		√	Yes	
	<i>2002-2003</i>	130.40	0.42	√	√	Vague	
	B	<i>2003-2007</i>	155.36.	0.38	√		Yes
		<i>2007-2008</i>	221.49	0.21	√		Yes

note: Average investment intensity(AII) is calculated by average investment (million yuan RMB) per km²; “√” indicates the significance in “high-density infill development” or “low-density expansion”; “match” means that R matches with EID or IID in a particular span of time.

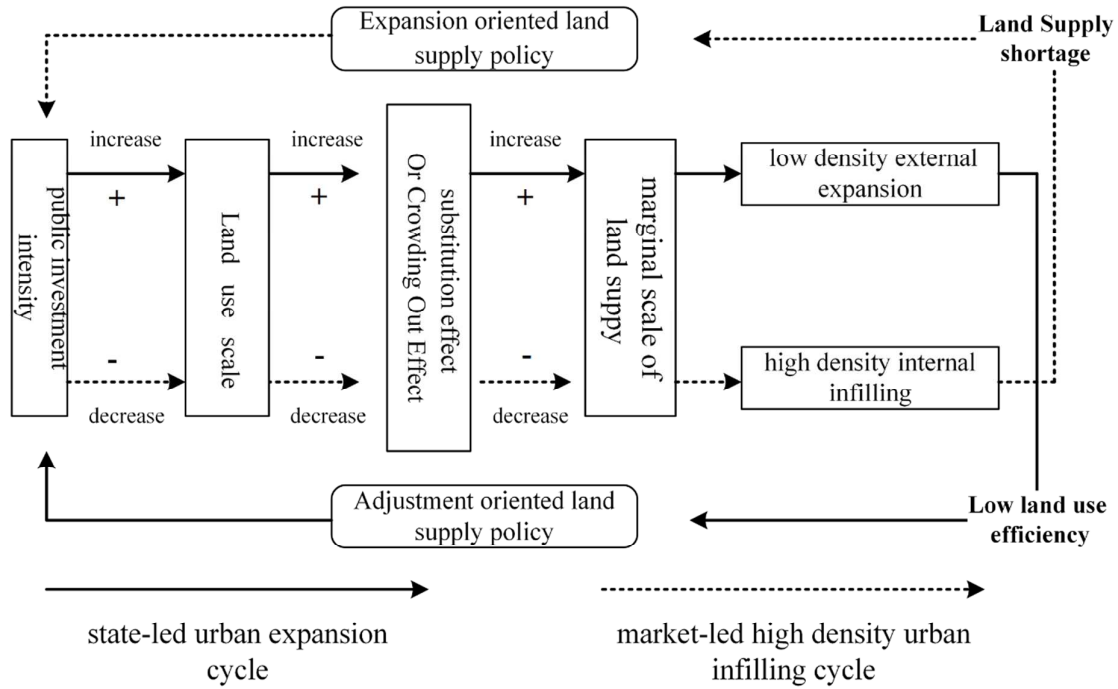
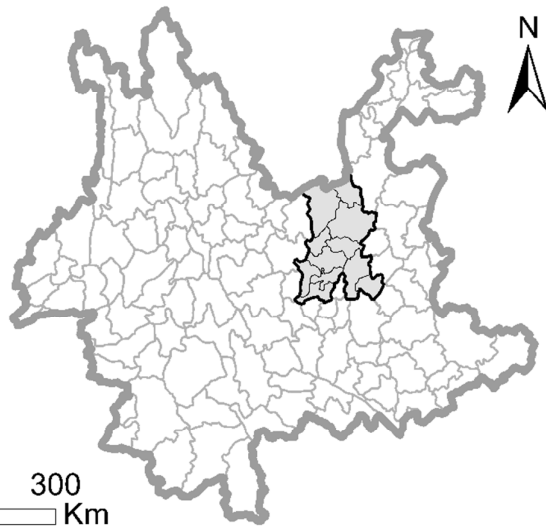


Figure 1: The dually dialectic forces of urban growth



Legend





-  Yunnan Border
-  Kunming Border
-  District Border
-  County Border

Figure 2.
Location of the
study area –
Kunming Municipality

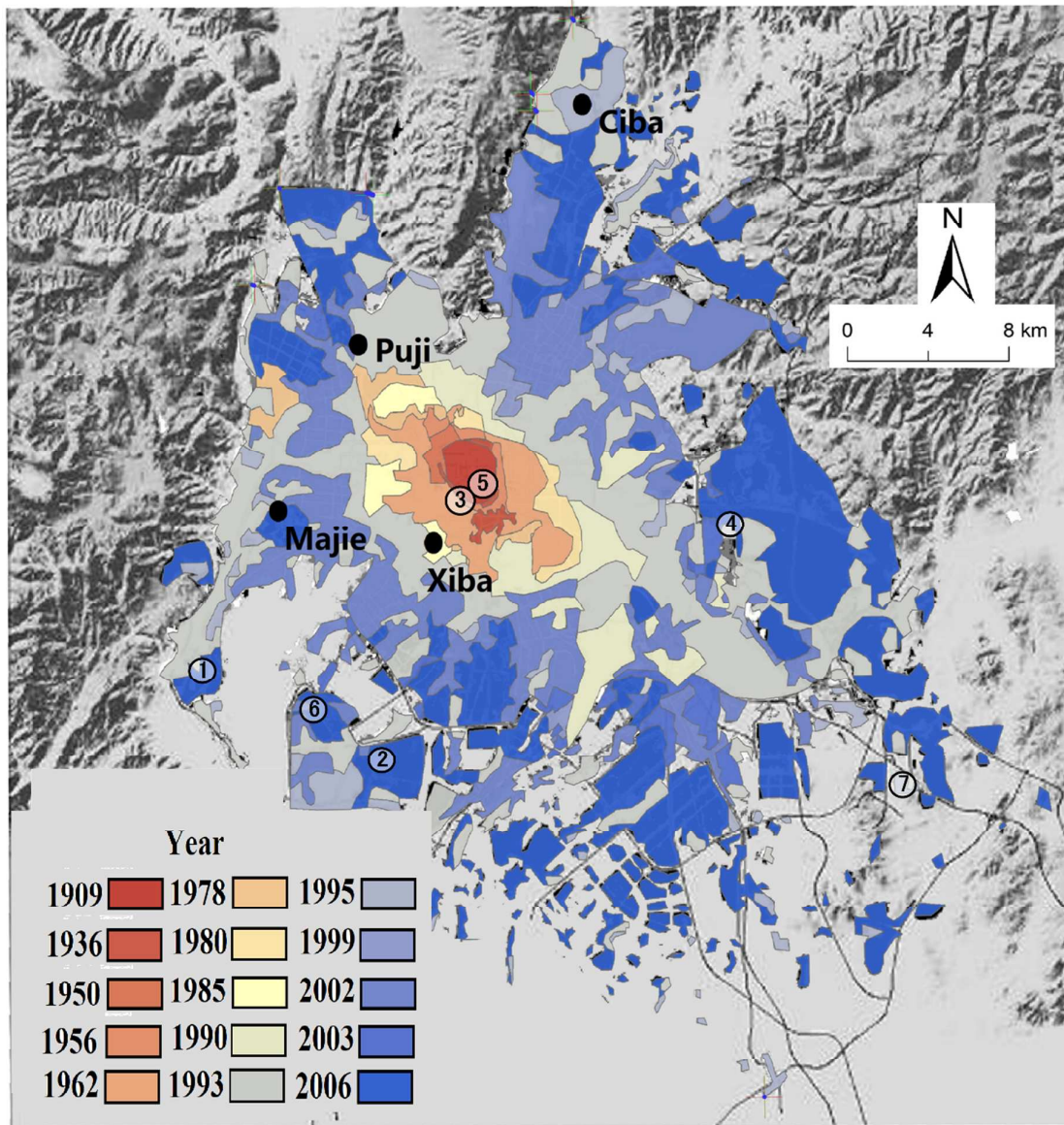


Figure 3. The morphological evolution of Kunming 1909 – 2006

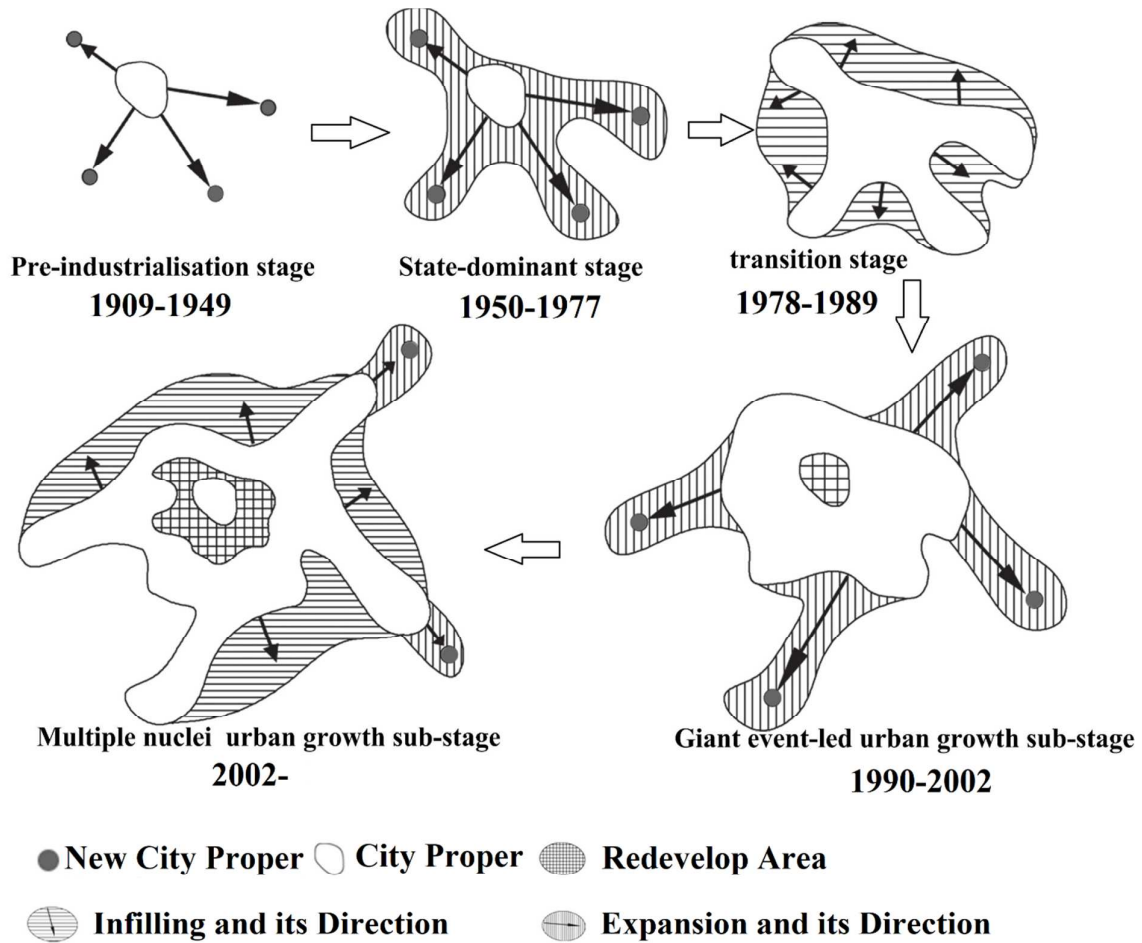


Figure 4. The five phases of urban growth of Kunming Metropolis from 1909 to 2014

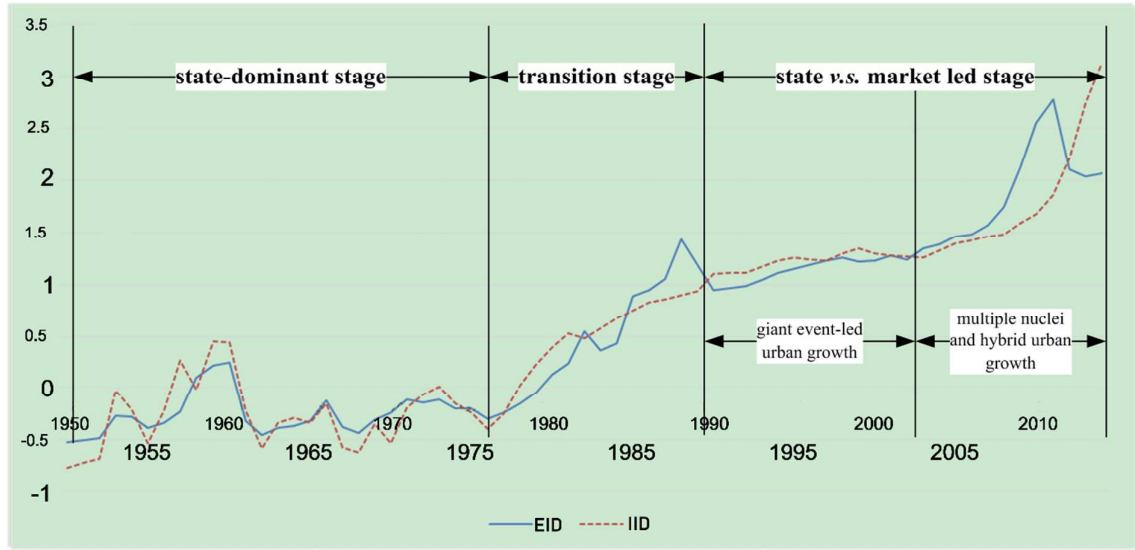


Figure 5. The temporal variations of two indicators (EID and IID) in Kunming since 1950

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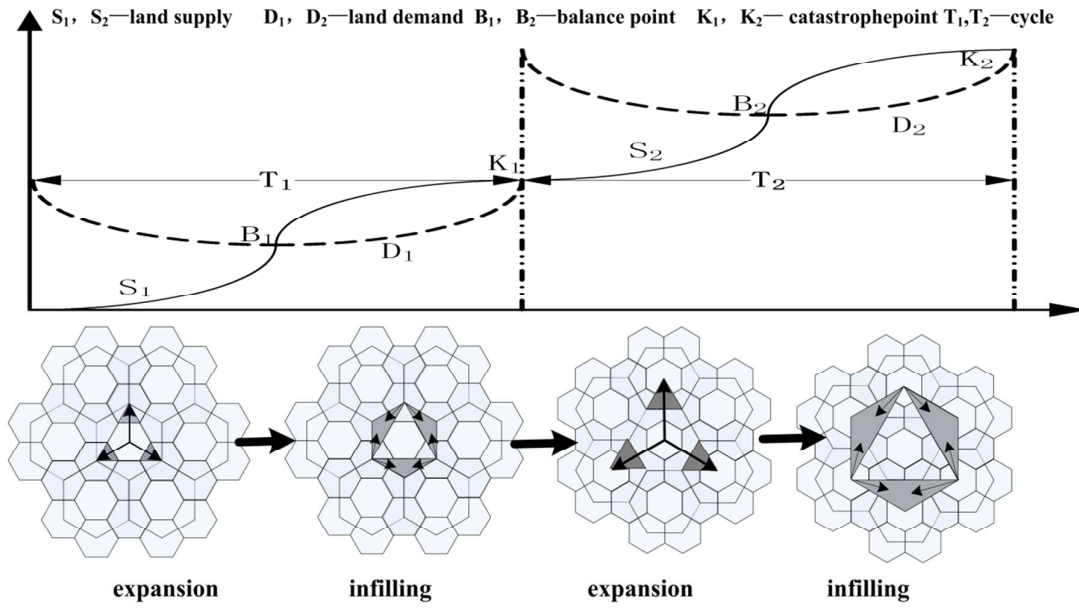
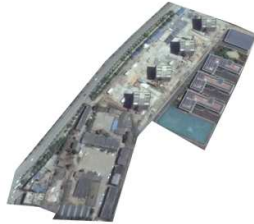


Figure 6. A cyclic growth model of urban morphological evolution

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Appendix 1: Examples of high-density infill development and low-density expansion at different stages (the location of each image is shown in Figure 3)



(1) Later 1990s



(2) Early 2000s



(3) Later 1990s and early 2000s



(4) Early 2000s



(5) First developed in 1950s,
then redeveloped in early 2010s



(6) Later 2000s



(7) Later 2000s