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Abstract

Urban–rural construction land transition (URCLT) and population flow serve as two significant issues in the global process of urban–rural transition development. Better understanding of URCLT and its coupling relationship with population flow has great significance for enriching the theory of land use transitions and coordinating human–land dynamics in this process. This study develops a theoretical model of URCLT based on the land use transition theory using the structure transition index of urban-rural construction land (LUUR). In addition, a decoupling model is utilized to reveal the relationship between URCLT and rural-to-urban population flow. Taking the Yangtze River Delta Urban Agglomeration of China as an example, the results shows that LUUR in the study area experienced a rapid rise and then steady ascension during 2000–2015. The spatial transition trend of LUUR decreased as the distance from urban downtown increased and noticeably rose in the suburbs in the study period. The relationship between URCLT and rural-to-urban population flow converted from coupling in 2000–2005 to weak decoupling state during 2005–2015 and displayed substantial regional differences. Regulating URCLT and properly coordinating its relationship with population flow can help stabilize urban–rural transition development in China.

Keywords: Land use transition, Urban-rural construction land, Coupling relationship, Population flow, Yangtze River Delta Urban Agglomeration

1. Introduction

The expansion of urban–rural construction land (URCL) and the flow of rural-to-urban population are two outstanding factors of urbanrural transition development (Díaz-Palacios-Sisternes, Ayuga, & García, 2014; Yang, Liu, Li, & Li, 2018). Discussions on them have been debated for a long time. Urban–rural transition makes labor, land and other elements transfer from rural areas to cities (Henderson & Wang, 2005; Ma, Chen, Fang, & Che, 2019). The migration of rural-to-urban population is the most direct manifestation of urban-rural transition development (Angel, 2002), which requires expanding urban construction land and rural residential land for production and living (Lambin, Turner, Geist, Agbola, et al., 2001). Under this circumstance, the spatial structure and landscape of urban and rural areas with land as the carrier change dramatically (Hudalah & Firman, 2012; Ma, Jiang, Li, & Zhou, 2018; Skog & Steinnes, 2016). This is a typical phenomenon in developing countries such as China (Liu, Liu, & Qi, 2015). Accelerated urban-rural transition has led to significant change in rural population. According to the Unit Nations (2011), the rural population of the world's least-developed countries will increase from 3.06 billion in 2010 to 3.12 billion in 2025, and then decrease to 2.87 billion in 2050. The growth and migration of rural population will have substantial effects on urban-rural land use (Song & Liu, 2014).

Recent changes in rural-to-urban population flow and land use change have been examined in China (Liu et al., 2015). Owning to tremendously rapid economic development since the country's reform and opening-up, China's urban population increased by 433 million and the rural population decreased by 275 million during 1996–2016. While urban construction land increased by 105.99% during 1996–2010 and the area increased by 2.29 million hm^2 in 2010–2016. However, rural residential land did not decrease according to theoretical prospection, but increased by 1.31% during 1996–2016 (Wang, Fang, & Li, 2014). This unreasonable human-land evolution between urban and rural areas occurs continually in many coastal regions of China, such as the Yangtze River Delta region and Pearl River Delta Region (Luo, Xing, Wu, Zhang, & Chen, 2018; Weng, 2002). Along with the flow of rural-to-urban population, the issue of urban-rural land use change and its relationship with population flow become a hot research topic in urban–rural development planning and decision making (Long, Ge, Zhang, & Tu, 2018). It is also an important field of land use transitions that can satisfy national strategic needs.

Land use transition research provides theoretical and practical guidance for optimally regulating the human-land relationship conflict that emerges in the process of urban-rural transition. (Grainger, 1995; Long & Qu, 2018; Meyfroidt, Rudel, & Lambin, 2010). At present, many scholars have conducted an in-depth research on urban-rural land use transitions, such as forest transition research (Mather, and Needle, 1997; Meyfroidt et al., 2010), farmland transition (Ge, Long, Zhang, & Li, 2018), rural settlement transition (Jiang, He, Qu, Zhang, & Meng, 2016; Ma et al., 2018), and other aspects(Yang, Jiang, Zheng, Zhou, & Li, 2019). The impact of land use transitions on grain production (Ge et al., 2018), and effects of land use transitions on ecosystem services have also contributed to these related studies (Long, Liu, Hou, Li, & Li, 2014).

A lot of researches have been conducted in land use transitions, but few studies have directly analyzed urban–rural construction land transition (URCLT) and explored its links with rural-to-urban population flow. URCLT refers to the transformation of URCL morphology in different temporal and spatial scales driven by socio-economic transitions (Lv, Huang, & Zhang, 2015). The core difference between URCLT and other land use transitions lies in the joint characteristics of land use types, mainly including urban construction land and rural residential land. Both are the spatial carrier in urban and rural areas where residents work and live, and they are more closely related to population flow. Existing studies on URCL change mainly focused on the scale (Mayer & Somerville, 2000; Xu et al., 2017), spatial–temporal pattern, driving mechanism (Guo, Hao, Li, et al., 2005), its resources and environmental effects (Li, Cai, Wu, & Wei, 2019; Long, Heilig, Li, & Zhang, 2007), and often analyze URCL change at the administrative unit scale based on statistical data (Liu, Liu, & Qi, 2015). However, scant theoretical and empirical research has targeted URCLT from the perspective of structural evolution. Along with the population outflow, the change pattern of "one falls and another rises" of URCL appears (Qu, Jiang, Tan, Wang, & Li, 2019), indicating that the structural evolution characteristics are an important manifestation of URCLT. These structural changes are particularly important given the fundamental reality that increasingly fierce structural conflicts occurred globally in the process of urban-rural transition development.

Since the 16th century, rural-to-urban population flow has been recognized as an important driver of local land use transition in Europe (Bell, Alves, de Oliveira, & Zuin, 2010). Following the decade of the 1960s, the population and land use change dynamic in developing countries have taken a similar path as Europe and other developed countries. When national or regional economics transformed from agriculture to industry, urban population and land increased while rural residential land declined and forests recovered (Brown, Johnson, Loveland, & Theobald, 2005; Chen, Ye, Cai, Xing, & Chen, 2014). Case studies in Latin America have been either conducted on rural-to-urban population flow and forest transition or focused on rural-to-urban population flow and deforestation (Aide & Grau, 2004; Grau & Aide, 2007). In recent decades, accelerated urbanization is triggering tremendous land use transitions in different parts of world, many studies have analyzed the coordination between land expansion and population growth during urbanization process, and revealed that the land area always expands faster than the population scale during the urbanization (Luo, Xing, et al., 2018; Seto, 2011). Some studies have also explored the dynamic relationship between population and settlement in rural areas (Song & Liu, 2014). The term "coupling" is used extensively in describing their interactive relationship (Luo, Xing, et al., 2018). Models and a series of techniques are employed to quantitatively analyze the dynamic relationship between land use transitions and population flow (Luo et al., 2018), such as decoupling model and Geographic Information System (GIS) technology (Macedo, Defries, Morton, Stickler, & Galford, 2011; Tapio, 2005). These studies focus more on the relationships between the amount or growth speed of construction land and population, and mostly consider urban and rural areas as discrete subjects of inquiry. However, there is still research gap in the coupling relationship between URCLT and rural-to-urban population flow from the prospective of urban-rural structure.

The aim of this paper is to illustrate how the theoretical model of URCLT combined with population flow could help bridge the research gap by removing the error associated with urban–rural land use structure in traditional administrative statistical unit-based calculations. Specifically, based on the theory of land use transitions, a theoretical model combined with population mobility for analyzing URCLT is established. Then, to remove the error associated with urban–rural land use structure in traditional administrative statistical unit-based calculations (Ge et al., 2018), a structural index of URCL (LUUR) at grid scale is utilized to provide more detailed spatial information for research on URCLT, which is a useful tool for further investigating URCLT process. A decoupling model is used to reveal the dynamic relationship between URCLT and rural-to-urban population flow, which can provide theoretical and practical operation guidance for coordinating the human-land relationship in the process of urban-rural transition development.

The structure of this paper is arranged as follows. Section 2 builds a theoretical model combined with for URCLT. Section 3 introduces the study area, data sources, and research methods. Section 4 analyzes URCLT and reveals the relationship between URCLT and rural-to-urban population flow. Section 5 discusses the results, theoretical contributions and policy suggestions of regulating URCLT and coordinating its relationship with rural-to-urban population flow. Section 6 concludes the study.

2. Theoretical models for URCLT

Land morphology is the core content of land use transitions, and it emphasizes a certain land use structure corresponding to a specific stage of economic and social development (Meyfroidt, Chowdhury, Bremond, Ellis, et al., 2018). URCL is a combination of land-use types, which consists of urban construction land and rural residential land. These two types are similar in structure and function, including residential land, industrial land, and public-facilities land, and they provide production, living, and leisure services for urban and rural residents (Jiang et al., 2016). However, clear differences are observed between the two in landscape form, land use intensity, land value, and location. These two types of land also differ in land property right in China, which results in a dual land management model between urban and rural areas (Tan, Wang, & Heerink, 2018). Given the intersection of commonness and characteristics of URCL, this study analyzes the URCLT using the structural index of URCL (LUUR) at grid scale.

2.1. Theoretical model for the temporal transition of URCL

A general consensus holds that rural-to-urban population flow plays a significant role in URCLT (Li et al., 2019; Long et al., 2018). The interaction between them also contributes to rural restructuring, which is a process of reshaping socioeconomic morphology and spatial pattern in response to the changes of elements in urban and rural transition development (Tu & Long, 2017). Zelinsky (1971) provided a hypothesis of the mobility transition model focusing on rural-to-urban migration and identified three main stages in the transition of a society. Here, this paper constructs a theoretical model for the temporal transition of URCL based on Zelinsky's hypothesis of mobility transition in the context of rural restructuring (Fig. 1a). In Zelinsky's model, the pre-modern traditional society is characterized by minimal rural-to-urban migration and small-scale subsistence agriculture. To feed the increasing population, rural residential land expansion occurs at the expense of agricultural land and other natural lands, resulting in a low level of LUUR. At the second stage, rural areas become a transitional society, which is the developing period of rural restructuring. At this stage, the interaction between urban and rural areas grows. The rural-to-urban population flow induces economics from agriculture to industrial (Zelinsky, 1971), leading to rapid urban expansion and rural areas abandonment (Long, Tu, Ge, Li, & Liu, 2016). These changes result in a rapid rise in LUUR. The third stage is an urban society with a slight change in rural population. At this stage, the population flow between urban and rural areas decreases, the scale and speed of new urban construction land slow down, and rural residential land continues to develop into towns, and idle rural land is reclaimed as farmland (Li, Long, Liu, & Tu, 2015). The rise of LUUR is gradually slow and becomes stable. Currently, most developing countries are in the transitional society (Aide & Grau, 2004). However, in transitional China, rural residential land has not decreased according to the theoretical perspective due to the dual-track structure of urban and rural land management, and the gap between $PUUR_t$ and $LUUR_t$ is widened at the second stage (shown in of the "$PUUR_t$–$LUUR_t$" curve in Fig. 1a). Overall, the temporal transition of URCL is closely related with rural–to–urban population flow. This evolution trend has triggered corresponding restructuring in rural China, and the transition time varies in different areas.

2.2. Theoretical model for the spatial transition of URCL

Spatial transition of URCL is significantly affected by the spatial structure of regional social economy (Lambin & Meyfroidt, 2011; Mayer & Somerville, 2000). Core–periphery theory created by Friedmann, an important spatial manifestation of urban–rural unbalanced development, can better explain the evolution of regional economic development and spatial structure (Friedmann, 1966). Thus, we construct the spatial transition model of URCL based on core-periphery theory to discuss the transition trend of LUUR in space (Fig. 1b). The core region in Friedmann's model is characterized by developed industry, abundant capital, and dense population (Friedmann, 1966). To meet the increasing land demand, a large amount of surrounding farmland and rural residential land is converted into urban construction land, resulting in a high level of LUUR in this region. As the distance from the core region increases, non-agricultural economic activities decrease, and population distribution gradually disperses (Friedmann, 2016). Agriculture and natural landscape dominate the peripheral region with LUUR at a low level. In rapid industrialization and urbanization, the flow of various elements in the core region and the peripheral region is frequent, and the core region expands outward continuously to drive the development of the entire region. During this process, URCL expands rapidly at the expense of much agricultural land and natural land occupation. At the junction of core region and peripheral region, land use changes are more dramatic, leading to a more pronounced rise in LUUR (Gao & Ma, 2015). Overall, the spatial transition of URCL is closely related to the spatial structure pattern of urban and rural social economy and is the manifestation of the rural reconstruction in a certain period of time.

3. Material and methods

3.1. Study area

The Yangtze River Delta Urban Agglomeration is located in the alluvial plain of the Yangtze River estuary (29°20′N to 32°24′N, 115°46′E to 123°25′E), and covers an area of 211.7 thousand km^2. In terms of topography, the Taihu Plain occupies its main body, with an elevation of 200–300 m in most areas (Fig. 2). According to the State Council's 2016 “Yangtze River Delta Urban Agglomeration Development Plan”, the Yangtze River Delta Urban Agglomeration has Shanghai as its center and includes nine cities of Jiangsu Province, eight cities of Zhejiang Province, and eight cities of Anhui Province. The region has become one of the most vigorous and developed areas in China due to its unique development advantages. The total population was 150 million, and GDP reached CNY 12.67 trillion in 2014 (NBSC, 2016).

The advancement of urbanization and industrialization has brought about huge expansion of construction land. In 2013, the total scale of construction land in the Yangtze River Delta Urban Agglomeration reached 36,153 km^2, and the intensity of land development reached 17.1% (NBSC, 2014), which was higher than the level of 15% of Japan's Pacific Coastal Urban Agglomeration. However, the efficiency of land development of the Yangtze River Delta Urban Agglomeration was far lower than that of Japan's. Extensive and uncontrolled expansion of construction land has led to rapid reduction of farmland and green ecological space, which seriously affected the structure and utilization efficiency of regional territorial space (Wu, Dennis, Huang, & Chen, 2017). Taking the Yangtze River Delta Urban Agglomeration as an example, this research on URCLT and its coupling relationship with ruralto-urban population flow can provide support for improving the efficiency of territorial space development in this area.

3.2. Research framework

During urban-rural transition development, URCLT and its relationship with rural-to-urban population flow becomes closer and more complex. To reveal the transition characteristics of URCL and its linkage, a research framework is developed to explore URCLT and its relationship with rural-to-urban population flow in the Yangtze River Delta Urban Agglomeration during 2000–2015 (Fig. 3). The framework contains four steps.

Step 1: “Create Fishnet” tool of ArcGIS and land use data are used to calculate the area of urban construction land and rural residential land at grid scale in the Yangtze River Delta Urban Agglomeration in 2000, 2005, 2010 and 2015. According to Zhou's research results, the analysis scale of nearly 4 × 4 km can fully retain the information of LUCC in the urban agglomeration around Hangzhou Bay of China (Zhou, Xu, & Wang, 2015). This study selects the 5 × 5 km grid scale as the spatial analysis unit considering the scope of the study area.

Step 2: The changes of urban construction land and rural residential land in each grid are calculated using “Raster calculator” tool of ArcGIS software. Hot spot analysis is utilized to analyze the hot area distribution of changes in urban construction land and rural residential land.

Step 3: A structure index of URCL is built to reflect its structure evolution characteristics. Multi-layer buffer analysis and hotspot analysis are used to analyze the temporal and spatial transitions of URCL.

Step 4: A decoupling model is used to reveal the relationship between URCLT and rural-to-urban population flow at prefecture-level city scale during 2000–2005, 2005–2010 and 2010–2015.

3.3. Data source

The data for analyzing URCL are based on a Chinese remotely sensed LUCC product for the four years (2000, 2005, 2010, and 2015) provided by Resource and Environment Data

Cloud Platform (http:// www.resdc.cn/). The classification system comprises farmland, forest, grassland, water area, URCL, and unused land. Here, URCL data are used as the research object, consisting of two main sub-classes based on urban construction land (cities, towns and industrial/mining land) and rural residential land. Deng, Huang, Rozelle, Zhang, and Li (2015) described the 2000–2015 accuracy assessment of the LUCC product, which has played an important role in national land resources surveys, and hydrology and ecology research. The socioeconomic statistical data of the prefecture-level city scale are derived from China's Provincial Statistical Yearbook. Various geographic data including administrative boundaries and administrative center are obtained from National Earth System Science Data sharing infrastructure (http://www.geodata.cn/).

3.4. Methods

3.4.1. Structure transition index of URCL

LUUR represents the proportion of UCL in URCL at each grid, which can reflect the land urbanization level from the perspective of URCL use structure (Guo et al., 2005). The formula of LUUR is expressed as follows:

$$LUUR_t = \frac{UCL_{tt}}{UCL_t + RRL_t} \times 100\% \quad (1)$$

$LUUR_t$ denotes the structure transition index of URCL in year t in each 5 × 5 km grid, UCL_t denotes the amount of UCL in year t in each grid, RRL_t denotes the area of RRL in year t in each grid, and LUUT indicates the change in LUUR in each grid, which is calculated as Eq. (2).

$$LUUT = \frac{LUUR_{t2} - LUUR_{t1}}{LUUR_{t1}} \quad (2)$$

where $LUUR_{t2}$ and $LUUR_{t1}$ denote the grid cell LUUR at the base period and end period, respectively.

3.4.2. Coupling analysis of URCLT and population urbanization

Theoretically, URCLT is closely related to rural-to-urban population flow, and the relationship between them is in a coupling state theoretically (Qu et al., 2019). If the flow of land or population elements is restricted between urban and rural areas, then a decoupling or negative decoupling state between URCLT and rural-to-urban population flow will emerge. This relationship can be quantitatively measured through a decoupling model. The formula is

$$T = \frac{(\overline{LUUR_{t2}} - \overline{LUUR_{t1}})/\overline{LUUR}_{t1}}{(PUUR_{t2} - PUUR_{t1})/PUUR_{t1}} \quad (4)$$

$$PUUR_t = \frac{U_t}{T_t} \times 100\% \quad (5)$$

$$PUUT = \frac{PUUR_{t2} - PUUR_{t1}}{PUUR_{t1}} \quad (6)$$

where TLUt denotes the coupling relationship state between URCLT and rural-to-urban population flow at city scale; $\overline{LUUR_{t2}}$ and $\overline{LUUR_{t1}}$ denote the mean grid-scale LUUR of city at base period and end period, respectively; $PUUR_{t2}$ and $PUUR_{t1}$ denote the population urbanization rate of city at base period and end period, respectively; and U_t and T_t denote the amount of urban population and total population, respectively.

According to Tapio's (2005) model classification, the relationship between URCLT and rural-to-urban population flow can be divided into three types, (i.e., negative decoupling, decoupling, and coupling), and includes eight logic possibilities. The specific classification and logic possibilities are summarized in Table 1. Relationships with T values 20% below or above

1.0 are defined as expansion coupling or recessive coupling, respectively. These eight types can potentially describe the coupling state between LUUR and PUUR. For example, recessive decoupling between LUUR and PUUR indicates that LUUR and PUUR both decrease (and T > 1.2). Strong decoupling indicates that increase in PUUR and a decrease in LUUR. By contrast, strong negative decoupling shows an increase in LUUR but a decrease in PUUR.

4. Results

*4.1. Spatiotemporal patt*erns of URCL

During 2000–2015, the total area of URCL in the Yangtze River Delta Urban Agglomeration increased by 8134 km^2 with a growth rate of 59.3%, and its expansion speed decreased first and then stabilized. In the same period, urban construction land growth scale was remarkable, with a total increase of 5739 km^2 over the past 15 years, accounting for 70% of the total increasing amount. Furthermore, urban construction land increased quickly during 2000–2005 and then remained stable during 2010–2015. Rural residential land increased relatively slowly. Its area increased by 2395 km^2 during 2000–2015, and its growth speed slowed down gradually. The hot spots of urban construction land expansion were spatially concentrated in three corridors between Shanghai and Nanjing city, Shanghai and Hangzhou city, and Hangzhou and Ningbo, presenting a Z-shaped spatial growth pattern (Fig. 4d). The hot spots of rural residential land growth mainly distributed in Shanghai and south of Jiangsu Province (Fig. 4h). Some urban construction land along coastal area of Jiangsu Province and rural residential land surrounding large cities decreased (Fig. 4c and g), which might be the result of the transition of industrial-mining land along the coast area of Jiangsu Province and the reclamation of idle rural land (Zhou et al., 2019).

4.2. Spatiotemporal transition characteristics of LUUR

During 2000–2015, the value of LUUR increased from 0.39 in 2000 to 0.48 in 2010 and to 0.50 in 2015, indicating that the temporal change of LUUR was generally consistent with the process model for the temporal transition of URCL proposed in this study. The growth rate of LUUR was rapid and then became slow. To further verify the regional characteristics of the temporal transition of URCL in different areas, a zoning statistical method was used to compare the change rate of LUUR across four regions across three periods. The results showed that Shanghai City had a slight URCLT trend, whereas the LUUR in Anhui Province experienced a rapid change. The LUUR changed dramatically in the rapid economic development areas but became slow in developed areas. These results generally verified the theoretical model of URCLT (Fig. 5).

The areas with high LUUR were spatially concentrated in large cities and along the coast of Jiangsu Province, whereas the low LUUR was mainly distributed in the west and north of the Yangtze River Delta Urban Agglomeration, especially in Anhui Province and Jiangsu Provinces (Fig. 6). In addition, the hot spots of the change in LUUR were mainly concentrated in Zhejiang Province and along the Yangtze River, which might be due to the transfer of coastal industries to inland areas, such as Zhejiang Province's Mountain and Sea Cooperation strategy and the emergence of urban agglomeration along the Yangtze River in Anhui Province (Wang, Du, & Liu, 2017).

To reveal spatial transition characteristics of URCL, the distance to the prefecture-level city center was selected to analyze the spatial evolution of LUUR by multi-layer buffer method. We found that LUUR was sensitive to the changes of distance to the urban downtown. The statistical analysis showed that the mean value of LUUR decreased as the distance from the downtown increased (Fig. 7a). In the urban areas (within 10 km), urban construction land accounted for approximately 15% of the total urban construction land area, whereas rural residential land occupied only 2% of the total rural residential land area. As the distance increased, the area of urban construction land gradually decreased, and rural residential land continuously increased. During 2000–2015, the fitting curve for LUUR in 2015 was higher than that in 2000. Fig. 7b presents the change rates of LUUR at different distances from the downtown. The LUUR continuously increased, and the growth rate peaked at the distance of 10 km and gradually declined after exceeding a distance of 10 km. These results were generally consistent with the theoretical model: the LUUR continuously decreased as the distance to the downtown increased, and the most evident growth of LUUR occurred in suburban areas.

4.3. Coupling relationship between LUUR and PUUR

Based on the changes in LUUR and PUUR, their relationship showed a coupling state, with an elasticity of 0.91 during 2000–2005; in 2005–2010 and 2010–2015, they exhibited a weak decoupling, with an elasticity of 0.21 and 0.15, respectively.

During 2000–2005, LUUR increased by 16.9%, whereas PUUR increased by 18.7%, implying a coupling relationship between them. The proportion of cities belonging to each category during this period was as follows: coupling (12%), expansive negative decoupling (23%), strong negative decoupling (19%), strong decoupling (11%) and weak decoupling (35%) (Fig. 8). Cities with weak decoupling state were mainly distributed in Jiangsu Province, whereas cities with expansive negative decoupling state were located in Zhejiang Province. During 2005–2010, many cities in Zhejiang Province converted from expansive negative decoupling into weak decoupling, and cities with weak decoupling occupied 69% of the total cities. During this period, LUUR increased only 5.8%, whereas PUUR increased 27%, leading to a weak decoupling state at the regional level. During 2010–2015, six cities converted from weak decoupling to coupling state, and several cities with weak decoupling shifted to expansive negative decoupling in the Yangtze River Delta Urban Agglomeration. Cities with coupling state were concentrated in the north of Zhejiang Province and the junction of Anhui and Jiangsu Provinces. During that time, LUUR increased 5.4% whereas PUUR increased 36%, resulting in a more evident state of weak decoupling. In Zhejiang Province, 38% of cities showed coupling, and 50% of cities exhibited weak decoupling. In Jiangsu Province, 56% of cities exhibited weak coupling.

In Anhui Province, 38% of cities showed coupling, whereas 38% of cities exhibited strong negative decoupling, and 24% of cities displayed expansive negative decoupling. Shanghai City continuously displayed strong decoupling. Overall, during 2000–2015, the relationship between LUUR and PUUR converted from coupling to weak coupling, and more cities converted to coupling state.

5. Discussion

5.1. Regulation of urban–rural construction land transition

URCLT is an important manifestation of urban–rural transitions development. In this study, URCLT is recognized as the temporal and spatial transitions of LUUR, which can help to better understand the structure evolution of URCL deeply, contributing to a theoretical basis for optimizing the URCLT. This paper established a theoretical model and applied a grid-scale statistical analysis to reveal that China's urban agglomeration region has experienced a significant URCLT caused socioeconomic development. URCLT is specifically manifested as a flattened S-shaped upward trend (Fig. 1a), which is generally consistent with the trend of population urbanization process (Wang et al., 2014). This evolution further proves that rural-to-urban population flow is closely related with URCLT (Chen et al., 2014). In terms of the spatial transition of URCL, URCLT showed a spatial pattern of high-core and low-peripheral areas and rose more evidently in the suburbs (Fig. 1b). This spatial evolution pattern is similar to that of urban spatial structure. The land development density of urban areas decreases gradually from the core area to the suburb (Jennings, 2006), indicating that the spatial transition of URCL is closely related with regional socioeconomic spatial structure. These remarkable characteristics of URCLT are the important features of urban-rural transition development under urbanization. An in-depth analysis on URCLT from the prospective of structural evolution provides critical insights into the dynamics of land use transitions. Combined with the special status of the Yangtze River Delta Urban Agglomeration in China's urbanization process, it is important to reveal the profound implications of URCLT for intensive urbanization.

During 2000–2015, the transition of URCL showed a growth in the scale of urban construction land and rural residential land, which was quite different from that in other countries. Between the 1910s and the 1970s, rural restructuring was identified in Western Europe, North America (Dahms, 1995), which was characterized by rural population loss, agriculture decline, and rural land reduction caused by rapid industrialization and urbanization. Since the 1970s, a general trend of “anti-urbanization” have been observed in developed countries. A series of new rural construction movements have been carried out to revitalize the countryside (Cei & Defrancesco, 2018), resulting in an increase of rural population and construction land. URCLT in developed countries has generally experienced a transition from “urban increase and rural decline” to “stable urban growth and reasonable rural increase”, showing a harmonious and stable human–land relationship between urban and rural areas (Chen et al., 2014). However, in rapidly urbanized China, the pace of URCLT is profoundly constrained by land management system (Tang, Mason, & Sun, 2012). China's land market is characterized by a dual-track system based on a division into urban and rural sectors. Under the dual urban–rural structure, the government actually controls rural–urban land market, and rural land cannot be transferred to urban areas directly (Tan, Wang, & Heerink, 2018). During urban and rural transition development, although the population of rural areas shows a decreasing trend, the scale of rural residential land shows an increasing trend because of the low cost of rural land (Long et al., 2007). This unreasonable structure of URCL further increases the pressure on farmland protection.

The URCLT can be effectively regulated to optimize the URCLT pattern. Land use planning is an effective policy tool in regulating land use pattern in the world (Xu et al., 2017). In 2019, China's central government proposed to build a unified territorial spatial planning system, aiming at restructuring urban–rural production, living and ecological space. In the future, the scientific establishment of planning standard is the key to the rational use of URCL and the important guarantee for the rational expansion of URCL. Farmland protection and the control of URCL scale are the crucial points of land-use planning. More importantly, the distribution of URCL should be optimized through spatial planning to improve the quality of urban and rural spatial development. A top-down level-to-level spatial planning system should be established to implement the development requirements and detailed control indicators of various functional areas level by level (Kong, Liu, & Fan, 2019).

5.2. Optimization of the coupling relationship between URCLT and rural-tourban population flow

Rural-to-urban population flow is an important driver of URCLT (Kates & Parris, 2003). This paper applied a decoupling model to reveal the dynamic relationship between URCTL and population flow from the prospective of urban-rural structure, which provides a theoretical foundation for coordinating the relationship of land use change and population flow between urban and rural areas. There is a transformation of relationship between URCLT and population flow from coupling to weak coupling state in the Yangtze River Delta Urban Agglomeration of China. The dynamic relationship between them from the prospective of urban-rural structural evolution is an important mean to study the human-land relationship in the process of urban-rural transition development. For the transitional China, it can provide important reference for urban-rural orderly transition and development (Yan, Chen, & Xia, 2018).

Urban and rural land use change is teleconnected through rural-tourban population flow (Seto et al., 2012). Thus, policies on population flow have a significant impact on urban and rural land use change, as in China and Vietnam before and after 1980s. The policy of controlling migration from rural to urban areas resulted in a relatively independent development of urban and rural areas. The policy form on liberalizing the restriction of population flow afterward accelerates the urban and rural transition development in developing countries (Chen et al., 2014). However, due to China's unique dual urban–rural land system, constraints on urban–rural land transfer led to an incoordination between URCLT and rural-to-urban population flow (Long, Li, Liu, Woods, & Zou, 2012). In this study, five kinds of sub-relationships between URCLT and rural-to-urban population flow were clearly revealed in the study area. These are namely, weak decoupling, strong decoupling, strong negative decoupling, expansive negative decoupling, and coupling relationships (Fig. 8). Among these relationships, the ideal condition for the relationship between LUUR and PUUR is coupling state, indicating a coordinating relationship between rural-to-urban population flow and URCLT. Other incoordination relationships between them are should be optimized through a series of policies on population management and land use.

In 2004, China's government proposed the Integrated Consolidation and Allocation of Rural-Urban Construction Land policy to provide construction land for economic development and control the total amount of construction land. This policy have achieved a number of successes, including the slowing down of farmland occupation, improvements to rural infrastructure and releasing the potential of rural land resources (Long et al., 2012). However, the ability of this policy to balance increasing urban land with decreasing rural construction at a country scale is questioned given the pre-existing geographies of uneven development (Long, Zou, & Liu, 2009). This study found a high demand for construction land in developed cities, such as Shanghai and Suzhou (decoupling state), with limited supply, but a low demand and plentiful supply of construction land in under-developed rural countries such as Chizhou and Taizhou (belong to negative decoupling state). Under the context that the integration development of urban agglomerations has become a national strategy in China (Chen, Legates, Zhao, & Fang, 2018), the Integrated Consolidation and Allocation of Rural-Urban Construction Land policy should be developed at regional, even national levels, to address the critical problem of balancing land demand and supply. More importantly, its successful implementation depends on integrating rural-to-urban population flow into regional development planning. An effective human–land linkage mechanism and a cross-regional urban–rural construction land market are suggested to promote the coordination of URCLT and population flow at regional scale. Therefore, the coordination of URCLT and population flow and the promotion of urban and rural integration development depend on the joint efforts of the regions. Specifically, in areas with decoupling state due to the slower transition of URCL, local governments should promote URCLT by accelerating the withdrawal and consolidation of rural idle land, urban renewal, and standard factory building (Long, 2012). In areas with negative decoupling state caused by slower rural-to-urban flow, the local government can accelerate population urbanization by lowing the requirements of rural population settling in cities, raising social welfare, and increasing employment opportunities. These measures contribute to the formation of coupling state (Fig. 9).

6. Conclusion

In the context of rapid urbanization, URCLT and rural-to-urban population flow jointly drive urban-rural transition. This study develops a theoretical model of URCLT based on the land use transition theory using the structure transition index of urban-rural construction land (LUUR). A decoupling model is utilized to reveal the relationship between URCLT and rural-to-urban population flow. Such conceptualization process of URCLT and population flow inter-relations could help reshape the ‘old’ views and replace with new discoveries of urban-rural construction land urbanization among global south countries such as China. In particular, this paper also attempts to fill in the research void by setting up the grid scale URCL index as a fundamental spatial unit to further investigate URCLT and the dynamic relationships between URCLT and rural-to-urban population flow. Using 5 × 5 km gridded LUUR data for statistical analysis, the results showed that the temporal transition of URCL experienced a transformation from rapid increase to steady growth. In addition, the spatial transition of URCL exhibited a decreasing trend as the distance from urban downtown increased and rose more evidently in the suburbs (5–15 km from the urban downtown) in this study period. Our findings validated the theoretical model of URCLT from the prospective of structure evolution.

A decoupling model was used to analyze the spatio-temporal relationship between LUUR and PUUR in the Yangtze River Delta Urban Agglomeration to help understand the incoordination of the URCLT and population flow. The results showed that their relationship changed from coupling to weak coupling state during 2000–2015, with substantial regional differences. Five kinds of sub-relationships were observed, and the number of cities with coupling state gradually increased. Based on the above results, detailed suggestions are put forward for policy improvement in two aspects, namely (1) scientifically formulating territorial spatial planning for regulating URCLT, (2) establishing an effective human–land linkage mechanism and a crossregional urban–rural construction land market at regional scale to promote the coordination of URCLT and population flow.

In transitional China, the coupling relationship between URCLT and population flow dominate the process of urban-rural transition. Thus, it is of great significance to deeply study the coupling relationship between URCLT and population flow in China, and to formulate regional regulation policy for URCLT and population flow. In the process of urban-rural transition development, the reasonable scale of URCLT from the perspective of man–land relationship will be the focus of future research. Moreover, the driving mechanism and modes of URCLT will be important contents to enrich the theoretical and empirical research of land use transitions.

Authorship contribution statement

- Congmou Zhu: Conceptualization, Methodology, Writing - original draft.

- Ke Wang: Investigation, Supervision.
- Xiaoling Zhang: Writing review & editing.
- Shaofeng Yuan: Visualization, Writing - review & editing.
- Lixia Yang: Methodology, Software, Writing - original draft.
- Martin Skitmore: Writing - review & editing.

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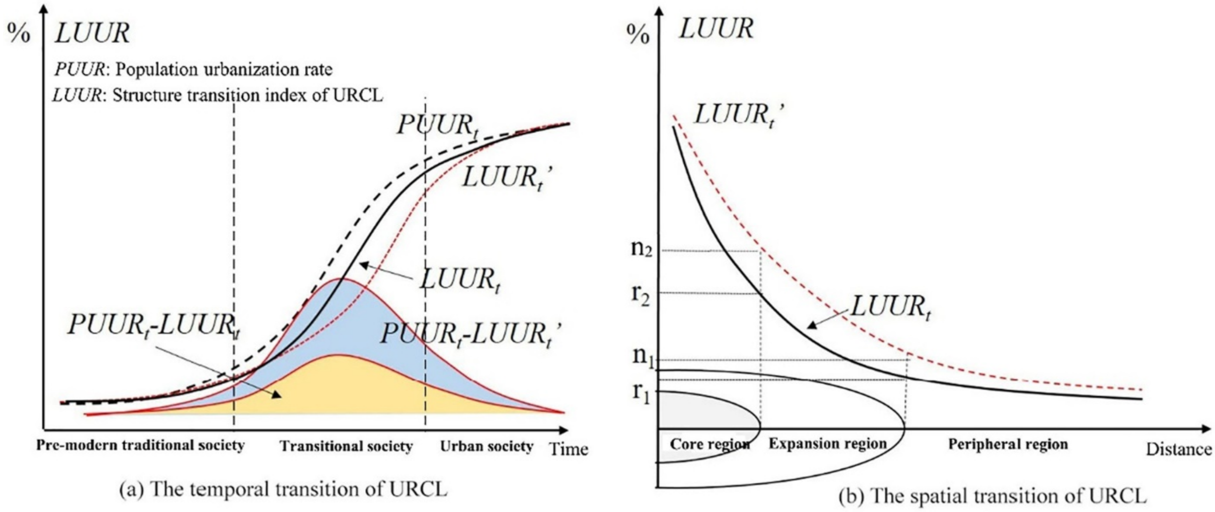

Fig. 1. Theory curve of URCLT.

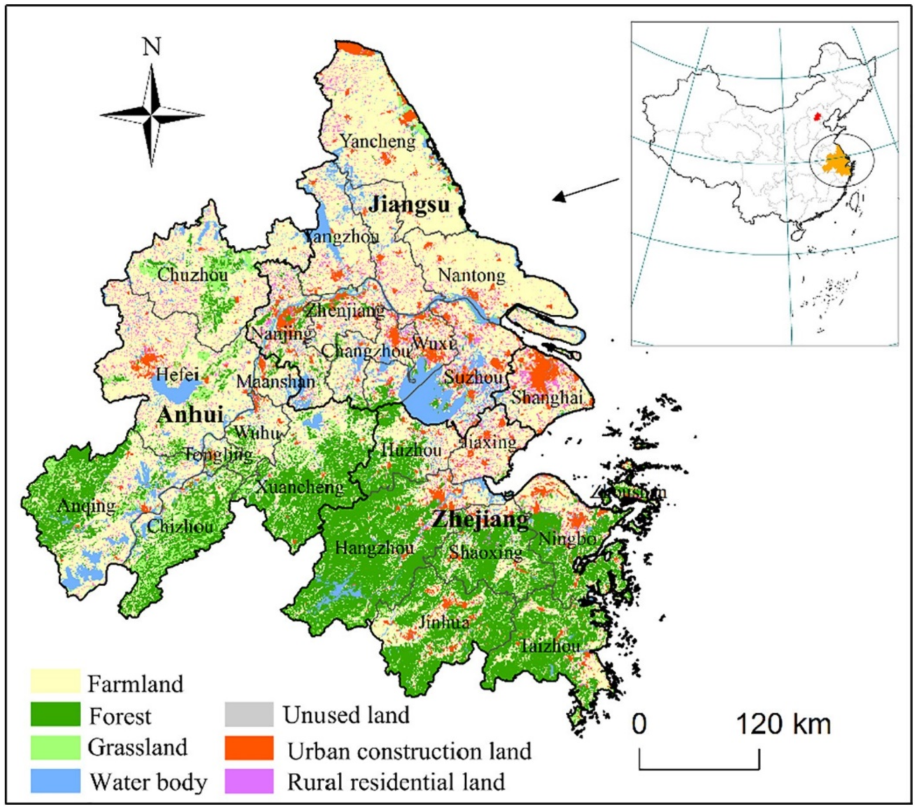

Fig. 2. Yangtze River Delta Urban Agglomeration (land use pattern in 2015).

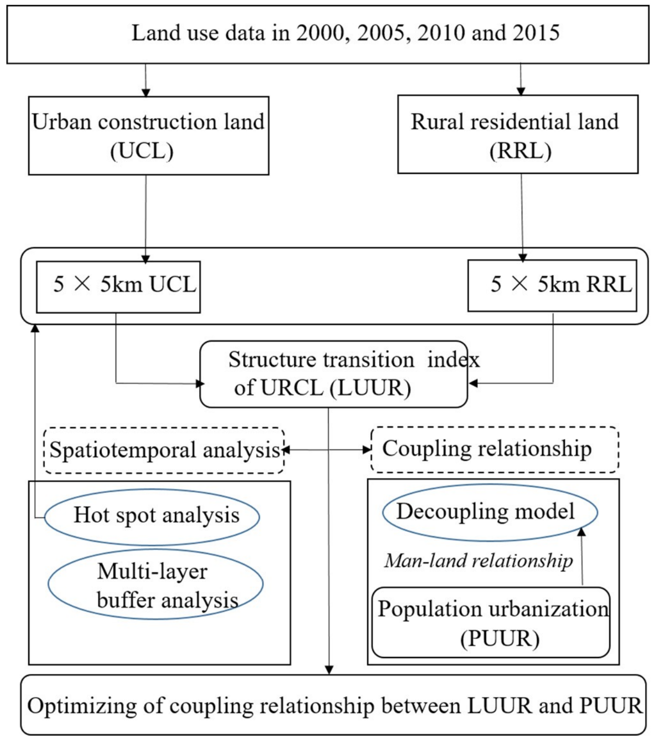

Fig. 3. Research framework.

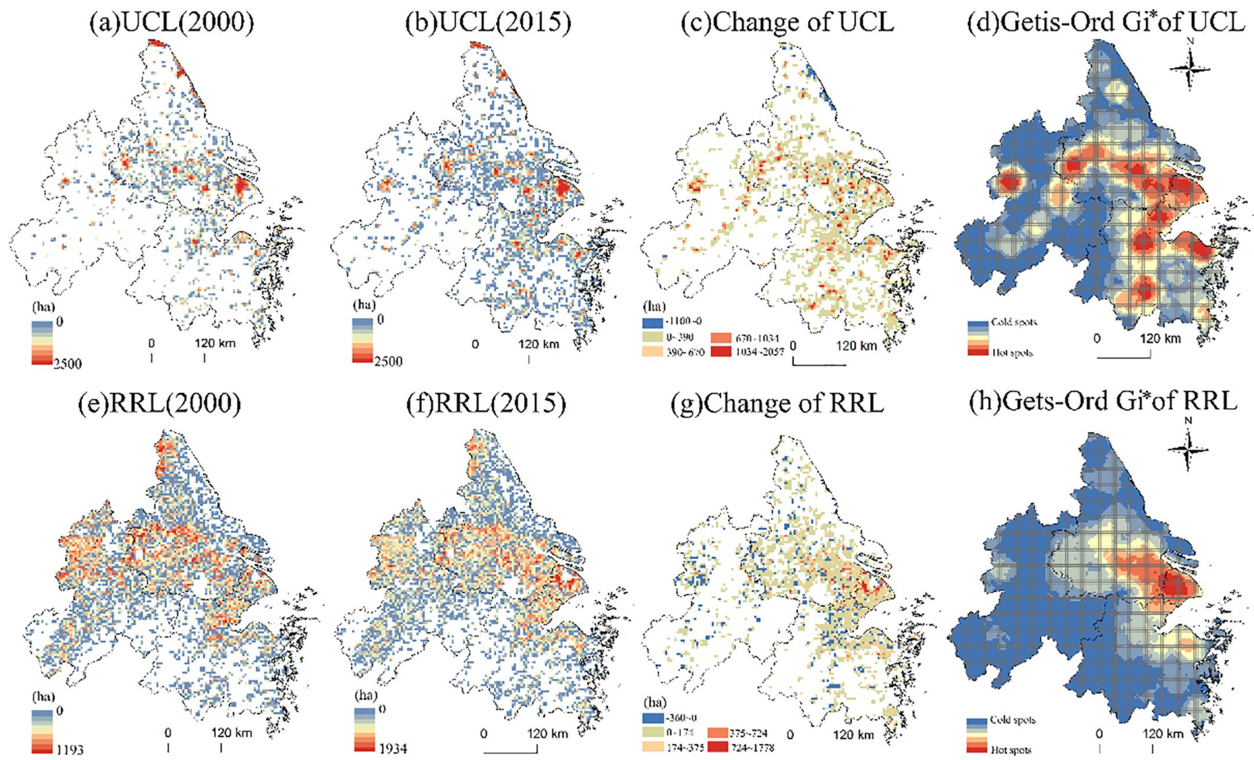

Fig. 4. Spatiotemporal patterns of urban construction land (UCL) and rural residential land (RRL) at 5 km grid during 2000–2015

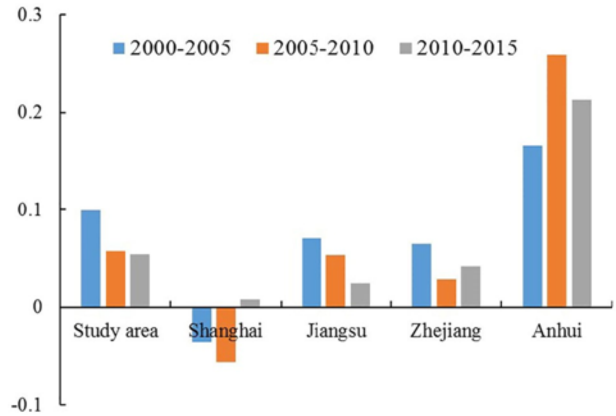

Fig. 5. Change rates of LUUR in different regions during 2000–2015.

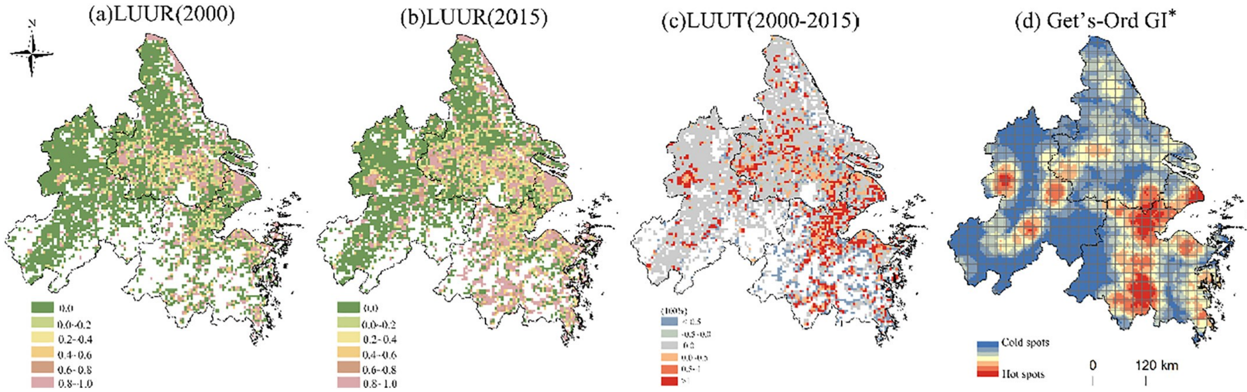

Fig. 6. Spatiotemporal patterns of LUUR at 5 km grid during 2000–2015.

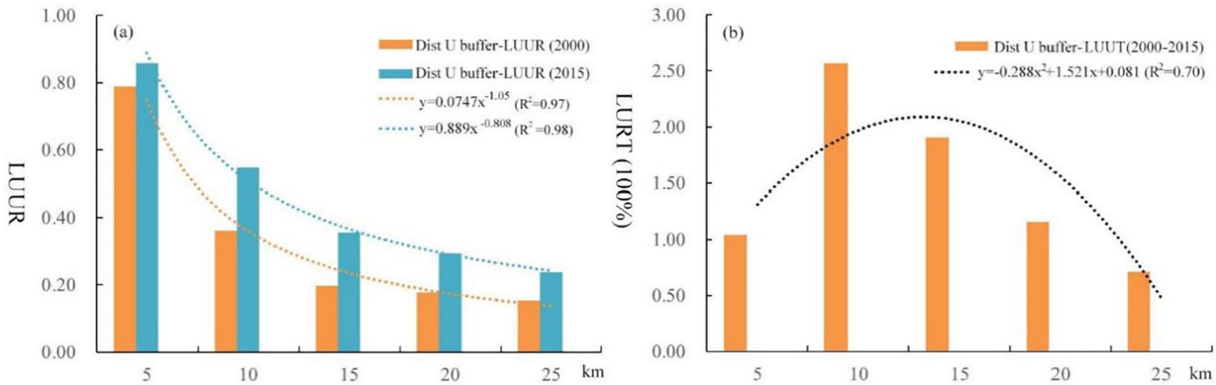

Fig. 7. Spatial change trends in LUUR at 5 km grid-scale during 2000–2015.

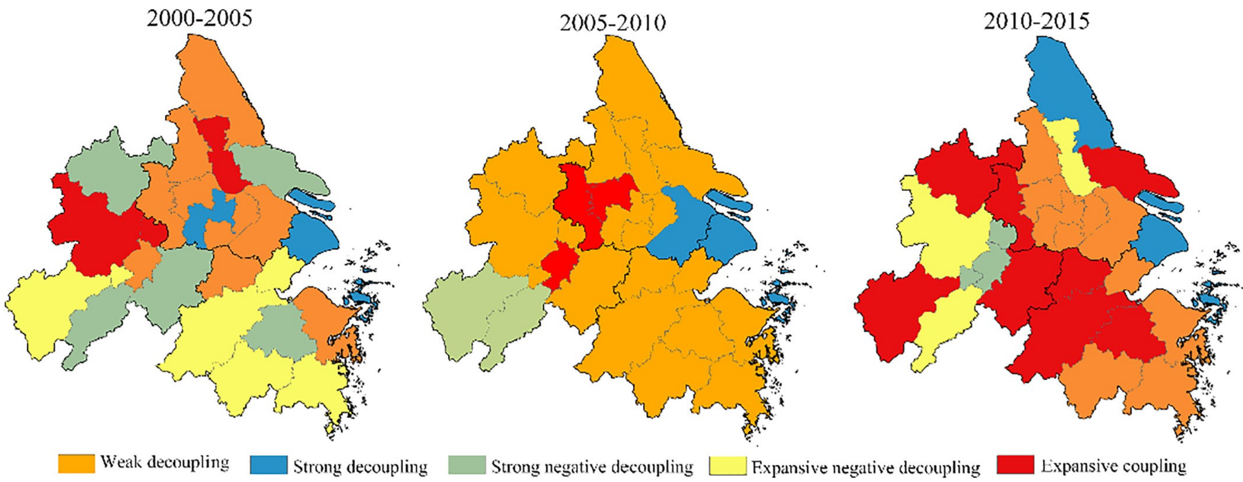

Fig. 8. Coupling state of LUUT and PUUT during 2000–2015.

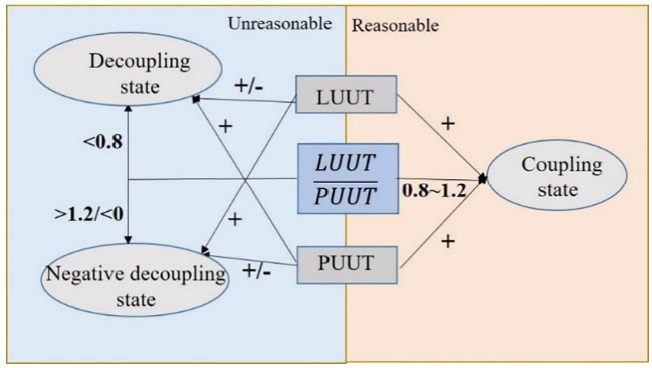

Fig. 9. Coupling relationship transition between LUUR and PUUR. "+"and "–" denote the increase and decrease in quantity, respectively.

Table 1

Classification of decoupling degree.

Decoupling types	Decoupling degree	LUUT	PUUT	T
Decoupling	Recessive decoupling	< 0	< 0	> 1.2
	Weak decoupling	> 0	> 0	0–0.8
	Strong decoupling	< 0	> 0	< 0
Coupling	Expansive coupling	> 0	> 0	0.8–1.2
	Recessive coupling	< 0	< 0	0.8–1.2
Negative decoupling	Expansive negative decoupling	> 0	> 0	> 1.2
	Weak negative decoupling	< 0	< 0	0–0.8
	Strong negative decoupling	> 0	< 0	< 0