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Citation

Guan, ChengHe, and Peter G Rowe. 2017. "In Pursuit of a Well-Balanced Network of Cities and Towns: A Case Study of the Changjiang Delta Region in China." *Environment and Planning B: Urban Analytics and City Science* (March 17): 239980831769607. doi:10.1177/2399808317696073.

Published version

<https://doi.org/10.1177/2399808317696073>

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In pursuit of a well-balanced urban network of cities and towns: A case study of the Changjiang Delta Region in China

ChengHe Guan and Peter G. Rowe

Abstract. Development of urban networks of cities and towns has received attention including discussions of tensions between population concentrations and overlaps with environmentally-sensitive and disaster-prone areas. Moreover, certain development in broad regions of China, such as its deltas, has become a subject of debate. Contrary to some assumptions, this development within places like the Changjiang Delta has proceeded in a relatively incremental manner. However, at this juncture, controlled development of larger cities, like Shanghai, has shifted to more conventional urbanization pathways forward involving larger city expansions. Nevertheless, further urban growth management appears to depend on development and maintenance of a well-balanced network of large, medium and small-scaled cities and towns. An important aspect of this development involves definition of the Changjiang Delta region itself, and in particular, alongside its likely further economic performance. To these ends, a scenario-based Cellular Automata model of spatial distribution is deployed, reflecting separate thematic projections. A baseline for economic performance is developed, incorporating measures of fixed asset investment in urban service, revenue from urban maintenance, and Gross Domestic Product. Revelation of a well-performing network involves spatial distribution of development at various scales, and in various concentrations within the region, moreover, location of this development, largely perpendicular to well-travelled corridors, appears as a preferable outcome, contrary to earlier depictions along the major transportation corridors.

Keywords: Network of cities and towns, scenario-based Cellular Automata, economic performance, disaster prevention, Changjiang Delta Region

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1. China's regional urban growth and management

China's regional urban growth, particularly in places like the Changjiang Delta, has contributed to a rise from under twenty percent of the total population living in urban circumstances around the time of the opening up in 1978, to slightly over 50 percent today. Remarkable though this transition may be in sheer magnitude of numbers, it took place generally under a gradualist approach without excessively high rates of change and with different broad strategies in place at different times (Rowe, 2011). It began with large cities, like Shanghai, remaining constrained in development against encouragement of smaller cities, towns and rural settlements. Commodification of urban activities, such as housing, was also pursued relatively aggressively, shifting urbanization into a more thoroughly marketized phenomenon. Responses to excessive duplication and fragmentation of economic activity, among other causes, were then pursued, including liberalization of larger cities and other places with comparative advantages (Guan and Rowe, 2017). More recently, this normalization of urbanization into relatively conventional pathways forward has been augmented by a new townization policy, which now places strong emphasis on community and life-style services and amenities in lower-tier cities and towns in order to stimulate domestic consumption, stabilize intra-urban migration, and improve the quality of life of citizens (Rowe and Guan, 2016). One of the other broad strategies in play, at least implicitly, is also a version of a 'third way' in spatial urban formation, whereby China takes advantage of its inherently bi-polar distribution of urban population among large and mid-sized cities versus smaller towns in order to secure a better future with regard to environmental and social qualities of life (Guan and Rowe, 2016). This is particularly apparent, at least potentially, in the Changjiang Delta, already the home to some 70 million inhabitants. It is also of high relevance to this study and the selection, development and deployment of empirical techniques with emphases on different scales of development, networking arrangements, infrastructure alignments, and relatively few background assumptions about future growth directions, results and outcomes.

2. Brief historical development of the Changjiang Delta region

Cities and regions were formally considered as systems or networks more than a half century ago (Batty, 1995). These networks were organized from the top down and also evolved from the bottom up (Batty, 2005 and 2012). The network system of the Changjiang Delta Region established its basic structure with a timeline that fits into Batty's description. Prior to the 1840s, the Changjiang Delta was an urbanized region. Suzhou, Yangzhou, Hangzhou, and Nanjing were the primary cities in the region. In addition to these cities, it was also populated by a dense pack of smaller towns and villages with a strong agricultural economy. Between 1840 and 1949, with the rise of Shanghai handling more than sixty-five percent of the national exports and imports, the delta region became a material distribution center by connecting sea trade with the Changjiang waterway transportation system (Keller et al., 2012). It was also the period during which both development in industry and the service sector flourished in Shanghai, making it one of the largest cities in the world. Then, from 1949 to 1978, a regime of highly-controlled urban development and a linear, rigidly hierarchical administration system was established. Some market towns lost their critical positions as circulation centers for agricultural products under a national uniform purchase policy. However, construction of basic agricultural infrastructure and communal industries laid the ground work for future local economic prosperity and in situ urbanization (Zhu, 2006). Chen and Sun, among others, even suggested that the city-town hierarchical system was becoming flat (Chen and Sun, 2007). With the historical opening up to the outside world in 1978, the Delta region then went through processes of controlled development of larger cities like Shanghai, coupled with encouraged development of smaller settlements. This began to change in the mid-to-late 1990s, with pursuit of more conventional urban pathways forward, and the substantial rise of Shanghai, in particular, as an international city. Today it dominates regional development, but not without a vast network quality to it, as well.

At this juncture, together with the Pearl River Delta and the Bohai Rim, the Changjiang Delta is one of the three most urbanized regions in China. In fact, its regional urban structure is more mature than most others in China. For example, the Bohai Rim which is still yet to become a true regional urban cluster is still developing. As such the Changjiang Delta is a good point of departure to examine future aspects of urbanization in China. Additionally, the economic capacity of the Changjiang Delta is extensive, much

larger than the Pearl River Delta and the Bohai Rim. In the latter region, even though the Bohai Rim might have great potential for further development from geographic and population points of view, the region must first surmount numerous difficulties, including a lack of natural resources like water. In addition, urban growth has concentrated to the two independently developed cities of Tianjin and Beijing.

3. Defining a boundary for the Changjiang Delta

Shanghai, the largest city in the Changjiang Delta region in terms of economic activities and international influences in the twenty-first century, is the so called ‘dragon head’ of the region. Consequently, some researchers use the administrative boundary of Shanghai Municipality, Jiangsu Province and Zhejiang Province as a study area. It is suitable for provincial level research. However, this definition is too ambiguous and arbitrary for the research on what can be called the Changjiang Delta regional urban system. The cultural barriers between the alluvial plains and mountainous regions are substantial, for example, Wenzhounese typically identify themselves as an independent group by language, education, and clan relationship. The economic dissimilarities are also extensive. The ‘Subei’ region, which is in the far north of the Changjiang, represented by Xuzhou among other cities, was developed much slower than southern counterparts.

The definition of Changjiang Delta region boundary is not stagnant but has fluctuated throughout history. However, its boundary has both spatial and temporal dimensions. The formation of the ‘Changjiang Delta Consortium’ and the annual Mayors conference is a convenient vantage point to review the growth process since 1993. In 1996, there were fifteen Cities: Changzhou, Hangzhou, Huzhou, Jiaxing, Nanjing, Nantong, Ningbo, Shanghai, Shaoxing, Suzhou, Taizhou, Wuxi, Yangzhou, Zhenjiang, and Zhoushan. In 2003, Taizhou was added. Again, in 2010, six more cities were incorporated including Hefei, Huaian, Jinhua, Ma’anshan, Quzhou, and Yancheng, to make a total membership of 22. The most recent increase of the consortium was in 2013. The affiliated cities were Chuzhou, Huainan, Lianyungang, Lishui, Suqian, Xuzhou, Wenzhou, and Wuhu. Currently, there are 30 cities in the Changjiang Delta Consortium. At this stage, however, not all 30 cities should be considered part of the regional urban system. The growth of the consortium is faster than the actual growth of the region. Wenzhou, for example, is historically developed from a very different economic and cultural background, as mentioned earlier. Geographically, it is appropriate to consider Wenzhou as an external element interacting with Changjiang Delta Region as a whole, rather than as an internal component of the system (Figure 1).

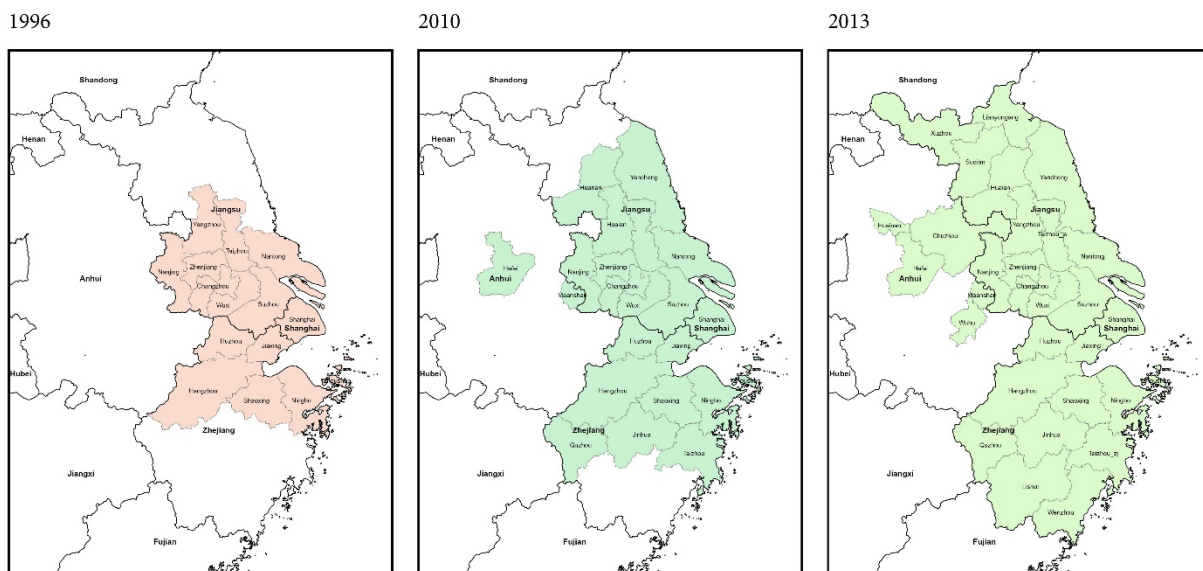


Figure 1. The spatial distribution of the Changjiang Delta Consortium 1996, 2010, and 2013.

4. The present structure of big, medium, and small-sized cities and towns

Among others, Marton explores the nature of the spatial economic restructuring in the lower Changjiang Delta (Marton, 2000). Instead of the core city expanding, many cities in Changjiang Delta show a reverse pattern. County-level cities have developed faster than peripheral areas of large cities. Interpretation can be made in two ways: one is by way of the multiple core of the urban employment area, the large city being the central core and the smaller county level cities being the multiple cores. The other is a deviation from the typical Urban Employment Area model. The central city is developed because of the peripheral urbanization. In both scenarios, results reveal that the regional differences widened (Marton, 2000). In the 1990s, an emerging pattern showed a lack of development in the adjacent area of Shanghai and Nanjing but relatively higher industrial production and urbanization in the country-side (Marton, 2000). The industrial development also coincided with high agricultural productivity. This supports a multi-centered regional urban formation. Zhang (2000) has suggested four types regional space structure model: V-shape, N-shape, and W-shape. Essentially, these are morphological shapes formed by nodes and links, in a network of settlements. The V-shape described an area expanding from Nanjing to Shanghai and then to Hangzhou, forming a geometry resembling the letter V. The N-shape extended the area from Hangzhou to Ningbo, hence the name N. The W-shape further stretched the region from Ningbo to Wenzhou.

Presently, the Changjiang Delta region, with the boundaries more or less specified by this discussion, is inhabited by urban settlements of a variety of scales and population sizes, as noted earlier. Partly as a legacy of the past and deeply entrenched agricultural practices, there are numerous small town and village settlements dispersed fairly evenly within the fertile plain of the delta. In addition, there are larger towns, many on their way to coveted definition as cities. Then there are cities, dominated by Shanghai with a total settlement population in excess of 20 million inhabitants, followed by Hangzhou, Suzhou, Wuxi, Changzhou and Nanjing, to name but a few of the relatively large cities in the region. Infrastructural development has also proceeded apace with development, including high-speed rail links among the mega-urban areas such as Ning-Hang High-speed Railway.

From the stand point of functioning as an ‘urban regional network’ and in harmony with both environmental and life-style circumstances, a well-developed and connected mix of big, medium-sized, and smaller urban settlements appears to offer advantages of alternative life style domains, more compact and intensive development, less pervasive cover of non-urban assets such as agricultural and conservation areas, and the diseconomies of excessive scale and over-population of particular cities. However, this is also conjectural and requires testing and further analysis. Moreover, at present in the Changjiang delta, the dynamics of development among settlements of varies size is in a state of flux. Based on the understanding of the past and present state regional urban structure of the Changjiang Delta Region, the research further evaluated and assessed the future growth potentials. This involved urban growth model prediction, including model identification, baseline development, and scenario construction. From there the predicted results were evaluated to provide suitable policy recommendations.

5. Data collection and processing

To measure and evaluate urban development and urban form, one group of researchers use indicators (Batty, 2013; Rowe et al., 2013). For example, ‘urban land consumption per capita’ is an indicator of urban form change. Historically, China’s major cities have a lower amount of amount of this indicator than other major cities in the world. However, this started changing in the 1980s. Measured by this indicator, Tianjin, for instance, has a thirty-four percent increase from 1988 to 2000 (Bertaud, 2007). Wei et al. studied ‘urban carrying capacity’, it provides policy makers key conceptual underpinnings to improve urban sustainability (Wei, 2016). Another useful indicator is ‘urban intensity’ measured by four related concepts: compactness, diversity, density, and connectivity. Together they lead to a single idea when considering spatial distributions potentially in a virtuous manner with regard to resource consumption, economic opportunity, social integration and environmental performance. (Guan & Rowe, 2016). Another group of scholars focused on simulation and projections (Batty and Xie, 1994; Liu, 2009; Samat & Elhadary, 2011). However, relatively few have done scenario-based simulation together with

basic ‘carrying capacity’ type investigations. The merit of this method is that it overcomes problems of a generic model by allowing incorporation of local specificity.

Time series and land-cover datasets were created for the years of 1950, 1970, 1980, 1990, 2000, and 2010. Years 1950 and 1970 were later dropped from the model calibration process because they represented a pattern of urban growth that dramatically differed from the post-economic reform era. Remote sensing images, historical maps, scanned planning, and geospatial data were collected and georeferenced. To specify standardized land-cover classes, on-screen visual interpretation was carried out using remote-sense images from the Landsat 5 and Landsat 7 series. The data sets were downloaded from the civilian Earth observation satellite, launched in July 23, 1972. Landsat 5 was launched in 1984 and delivers global data of Earth’s land surfaces for more than two decades. The Landsat 7 was launched in 1999. The two sets of images were used together to compensate for the weather-related unrecognizable portion of the available images.

The data were processed in the ArcMap environment and georeferenced to the Xian 1980 GK zone 19 coordinate system. The Scenario Cellular Automata models were set up under a UNIX operation system. The resulting images were reinserted back to the ArcMap conditions with specific scale and alignment to trace the original data ordinance and boundaries. The manually input data were collected in Excel and the normalization process used the formula:

$$\text{Normalized}(ei) = \frac{\ln(ei) - E_{min}}{E_{max} - E_{min}}$$

Where

E_{min} the minimum value for variable E

E_{max} the maximum value for variable E

If E_{max} is equal to E_{min} then Normalized (ei) is set to 0.5

6. Modeling modifications and change of parameters

This research chooses Cellular Automata models over other simulation models, such as agent-based model or a Lowry model, because of the minimum number of variables to be considered, the land-based algorithm, and the spatial mosaic characteristics of the cells to compare with economic performances. Among the different types of Cellular Automata models, the SLEUTH model was developed by Clark and Gaydos to simulate long term urban growth (Clark and Gaydos, 1998). The SLEUTH model runs with a series of parameters including slope, land use, excluded, urban, transportation, and hillshade. A scenario-based Cellular Automata model was developed based on the algorithm of a Cellular Automata model and a SLEUTH model and using their scripts with additional variables that guide and control the growth pattern. The modification of parameters did not change how the principles of the Cellular Automata model operated. However, they did provide opportunities to reflect the influences of certain urban policies on the outcome of the urban land growth patterns predictions (Guan and Rowe, 2016). The scenario-based Cellular Automata model used the formula:

$$G_{total}^{t+1} = \sum G_{spontaneous(i,j)}^{t+1} + G_{spread(i,j)}^{t+1} + G_{edge(i,j)}^{t+1} + G_{road(i,j)}^{t+1} + G_{corridor(i,j)}^{t+1} + G_{scenarios(i,j)}^{t+1}$$

Where,

G_{total}^{t+1} = Total urban growth prediction, at year t+1

$G_{spontaneous(i,j)}^{t+1}$ = Spontaneous growth, the occurrence of random urbanization of land, at year t+1

$G_{spread(i,j)}^{t+1}$ = Spread growth, the urban spreading of newly urbanized land cell, at year t+1 (pay attention that this excluded the spread growth of existing urbanized land cell)

$G_{edge(i,j)}^{t+1}$ = Edge growth, the further expansion of newly spread urbanized cell, at year t+1

$G_{road(i,j)}^{t+1}$ = Road influenced growth, at year t+1

$G_{corridor}^{t+1}(i,j)$ = Development corridor growth, at year t+1

The scenarios variables, in the research, includes:

$G_{city}^{t+1}(i,j)$ = Big cities growth, at year t+1

$G_{ecological}^{t+1}(i,j)$ = Ecological system concerns, at year t+1

$G_{disaster}^{t+1}(i,j)$ = Disaster preventions growth, at year t+1

Multiple scenarios were proposed and each of these scenarios prescribed a basic trajectory of development with unique features. Among them is the scenario on disaster prevention. The criteria used in this scenario is natural hazards and challenges associated with climate change. The natural disasters are those occurring physical phenome caused by rapid or slow onset events (International Federation of Red Cross, 2016). The categories included are geophysical, hydrological, climatological, and meteoroidal disasters. Biological and epidemics are not included. Geophysical hazards are earthquakes, landslides, and tsunamis; Hydrological hazards are floods; Climatological are extreme temperatures, drought and wildfires; and meteorological are storms and wave surges (International Federation of Red Cross, 2016).

7. Baseline conditions of economic performance

To measure economic performance, there are many factors such as purchasing power, levels of savings and savings ratios, price level and inflation, trade deficits and surpluses, growth in real national income, among others. There are also readily established related indices, such as the Human Development Index (HDI) which measures literacy rates and health care provision, and the Human Poverty Index (HPI) which measures of human poverty. Other theories particularly emphasize the potential for innovation and knowledge spillovers and the composition of economic activity (Glaeser et al., 1992, Fujita et al., 1999, Delgado et al, 2014).

In this research, the focus was on how economic performance of current administrative land areas can be associated with predicted urban growth. Here, economic performance was represented by both growth potential and current economic conditions. They were measured by intrinsic conditions and relevant conditions. In this exercise, the intrinsic conditions referred to those within the administrative boundaries, and the relevant conditions referred to those measured with regard to neighboring cities and towns. The selection of intrinsic variables was challenging because many of the indices were correlated and data collection at the city and town level was also problematic and often encountered issues, such as data inconsistency. The strategy was to include the most representative variables that represent productivity, investment, and revenue. There are many variables measuring productivity, among them the Gross Domestic Product (GDP) is most commonly used. GDP per capita or GDP per square kilometers was the most recognizable proxy for production. In this research, data on GDP from 2010 were selected as the baseline for economic performance. The numbers were acquired from China Statistical Yearbook 2011, Provincial Statistical Yearbooks 2011, as well as some city level statistical yearbooks.

On the investment side, national fixed-asset investment in urban service facilities was selected. It included financial allocation from the central government budget, financial allocation from the local government budget, domestic loans, securities, foreign investments and foreign direct investments, and self-raised funds and self-owned funds. However, it didn't cover urban public transport facilities. Even so this list of variables provided a relatively comprehensive measurement of urban fixed-asset investment. On the revenue side, the revenue of urban maintenance was selected. It included urban maintenance and construction tax, extra-charges for municipal utilities, fees for expansion of municipal utilities capacity, fees for use of municipal utilities, tolls on roads and bridges, water treatment fees, garbage treatment fees, land transfer revenues, water resource fees, and revenues. This list, in effect, was composed of almost all of the major revenues associated with urban maintenance. The data were collected from the China Urban Construction Statistical Yearbook 2011, the Zhejiang Province Statistical Yearbook 2011, the Jiangsu Province Statistical Yearbook 2011, the Shanghai Statistical Yearbook 2011, and other supplementary city and township level yearbooks and related materials.

Road access or road length per capita was considered to be one of the variables but was dropped from the equation as the category of ‘road’ and ‘conditions’ were hard to evaluate. For those areas lacking in information, data were used from one level up the administrative hierarchy in order to fill in the blank. Then, the three variables describing intrinsic conditions of urban economic performance, GDP per capita, national fixed-asset investment, and urban maintenance revenue were consolidated into an economic performance index (EPI), using weighted linear combination (WLC) method. The equation used was as follows:

$$EPI = \sum_{i=1}^n f(y_i * w_i)$$

Where,

EPI the economic performance index for intrinsic variables
f a normalization function
y_i the criterion selected
w_i the weighting for each criterion
n the total number of criteria

8. Results

One of the main goals of this research is to identify the economic competitiveness of cities and towns, and overlay the outcome with the results from simulation using scenario-based Cellular Automata models. The simulation result of disaster prevention is shown in **Figure 2**. Disaster prevention has become increasingly more important as natural disasters of many kinds, in recent years, destroyed human habitats of various cultures. Throughout human history, the natural forces have caused numerous catastrophes buried lives, cities, and civilizations. As cities grow bigger and urbanization brings higher concentrations of humanity, the consequences of these events potentially rise substantially. Preventive action is critical in the process of directing future urbanization. Consequently, simply avoiding development on disaster-prone locations can preclude many unnecessary costs, which precluded many harmful events to the individuals who live in the area. Fukushima’s nuclear explosion caused by a tsunami is one example of the extreme penalties experienced of natural disasters. New Orleans, another good example, is even under discussion as to whether or not it is a place appropriate for living (Munasinghe, 2007). In other regions, Nepal, the recent earthquake also gives indication where urban growth could avoid potential damages from natural forces. In the Changjiang Delta Region, earthquake and fault lines, as well as flooding are the major hazards, the latter aggravated by land-surface subsidence.

The results for economic performance were classified with natural breaks into ten categories, as shown in **Figure 3**. As the three categories of variables concerning economic performances were projected in the ArcGIS, together with the EPI, we uncovered revealed the basic economic conditions of the Changjiang Delta Region as follows:

- (1) Investment: Shanghai and Nanjing, as well as some high value cities north of Lake Tai, such as Wuxi, were the most prominent;
- (2) Revenue: Shanghai, Nanjing, and Hangzhou composed the tripod of the region. Some other high value cities were located north of Lake Tai, such as Suzhou;
- (3) GDP: Shanghai was the ‘dragon head’ leading the economic growth of the Changjiang Delta Region.

These observations provided a good point of departure for understanding the economic performance and the projection of future urban growth of the region. In this research, data normalization was used to prepare the variable input for the WLC calculation. Here normalization used natural logarithmic values to eliminate outliers and then the logarithmic numbers were scaled between zero and one. **Table 1** revealed the results normalization process and the EPI of each city and their relative rankings within the Changjiang Delta Region urban network.

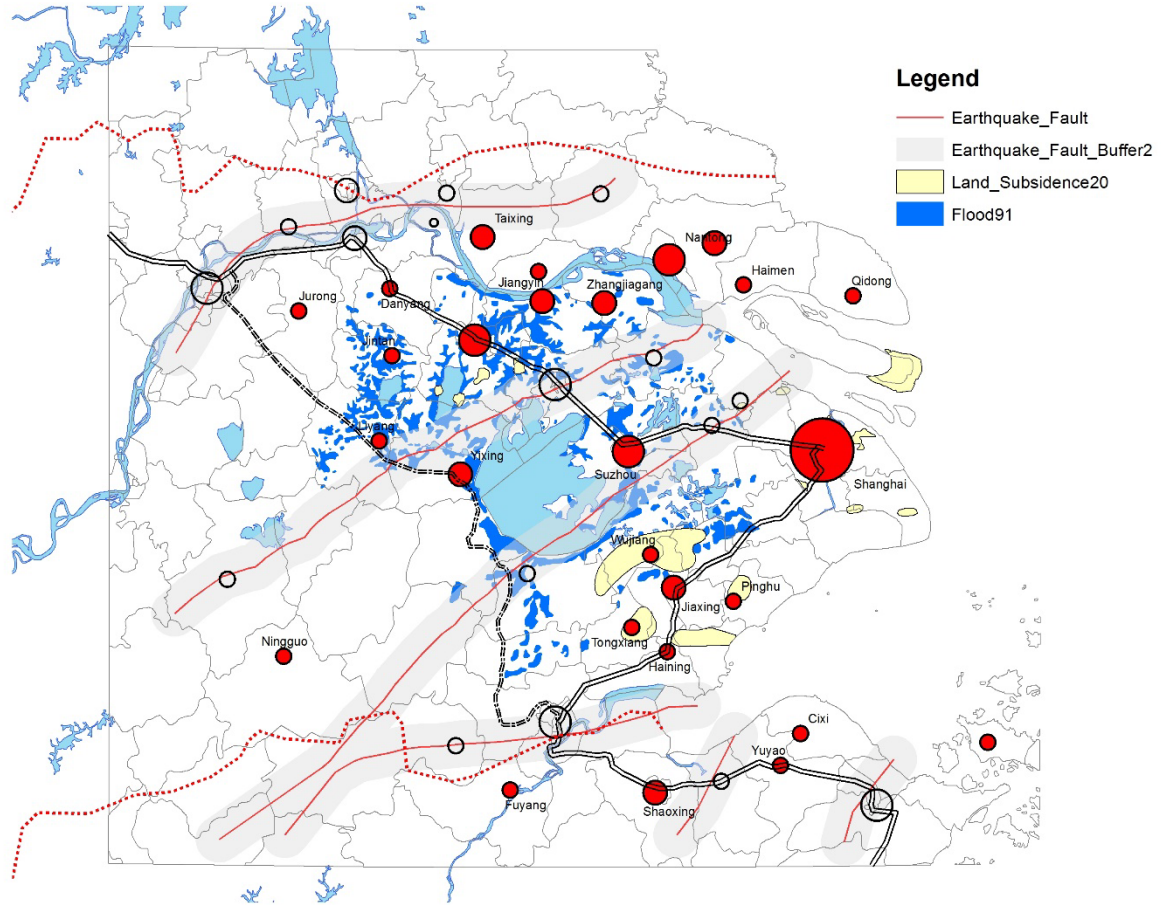
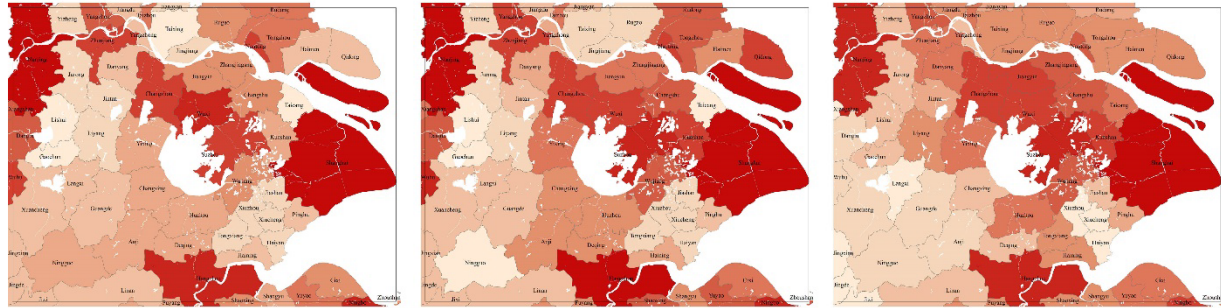


Figure 2. Disaster prevention.



The National Fixed Asset Investment

- financial allocation from the central government budget
- financial allocation from the local government budget
- domestic loan
- securities
- foreign investment and foreign direct investment
- self-raised funds and self-owned funds

The Revenue of Urban Maintenance

- urban maintenance and construction tax
- extra-charges for municipal utilities
- fee for expansion of municipal utilities capacity
- fee for use of municipal utilities
- tolls on roads and bridges
- water treatment fee
- garbage treatment fee
- land transfer revenue
- water resource fee
- revenues

Gross Domestic Product

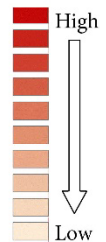


Figure 3. EPI composition by cities and counties.

Table 1. Economic performance normalizations, scores, and rankings, 2010.

Rank	City	Province	Natural Logarithm of Investment	Natural Logarithm of Revenue	Natural Logarithm of GDP	Normalizing Investment (0-1)	Normalizing Revenue (0-1)	Normalizing GDP (0-1)	Economic Performance Scores
1	Shanghai	Shanghai	15.2949	14.6043	9.7393	1.0000	0.9975	1.0000	0.9992
2	Nanjing	Jiangsu	14.9349	14.5300	8.4152	0.9765	0.9924	0.8640	0.9443
3	Hangzhou	Zhejiang	14.0894	14.6406	8.4640	0.9212	1.0000	0.8691	0.9301
4	Suzhou	Jiangsu	13.8714	14.0090	8.1811	0.9069	0.9569	0.8400	0.9013
5	Ningbo	Zhejiang	14.3478	13.7286	8.0269	0.9381	0.9377	0.8242	0.9000
6	Wuxi	Jiangsu	14.3892	13.1352	8.0019	0.9408	0.8972	0.8216	0.8865
7	Changzhou	Jiangsu	13.4605	12.6468	7.7477	0.8801	0.8638	0.7955	0.8465
8	Nantong	Jiangsu	13.8315	12.0355	7.2391	0.9043	0.8904	0.7433	0.8460
9	Zhenjiang	Jiangsu	13.6497	12.9249	6.7392	0.8924	0.8828	0.6920	0.8224
10	Yangzhou	Jiangsu	12.9200	12.7244	6.8971	0.8447	0.8691	0.7082	0.8073
11	Kunshan	Jiangsu	11.4089	12.7028	7.6498	0.7459	0.8676	0.7855	0.7997
12	Zhangjiagang	Jiangsu	11.8391	11.9520	7.3800	0.7741	0.8164	0.7578	0.7827
13	Jiangyin	Jiangsu	11.6560	11.7437	7.6014	0.7621	0.8021	0.7805	0.7816
14	Changshu	Jiangsu	11.4709	12.1705	7.2818	0.7500	0.8313	0.7477	0.7763
15	Wujiang	Jiangsu	11.5058	12.3323	6.9111	0.7523	0.8423	0.7096	0.7681
16	Yuyao	Zhejiang	12.1502	12.3061	6.3419	0.7944	0.8405	0.6512	0.7620
17	Wuhu	Anhui	13.5516	13.5144	4.6347	0.8860	0.9231	0.4759	0.7617
18	Tongzhou	Jiangsu	12.1096	12.2473	6.2305	0.7917	0.8365	0.6397	0.7560
19	Taizhou	Jiangsu	12.3312	11.8605	6.3395	0.8062	0.8101	0.6509	0.7558
20	Cixi	Zhejiang	11.5282	11.8712	6.6299	0.7537	0.8108	0.6807	0.7484
21	Rudong	Jiangsu	12.1096	12.4623	5.8647	0.7917	0.8512	0.6022	0.7484
22	Yixing	Jiangsu	11.3317	11.8739	6.6919	0.7409	0.8110	0.6871	0.7463
23	Zhoushan	Zhejiang	11.7442	12.1463	6.1236	0.7678	0.8296	0.6288	0.7421
24	Dangtu	Anhui	12.5968	12.5238	5.2439	0.8236	0.8554	0.5384	0.7391
25	Shaoxing	Zhejiang	11.5312	12.1871	6.1457	0.7539	0.8324	0.6310	0.7391
26	Qidong	Jiangsu	10.5711	12.7596	6.0639	0.6912	0.8715	0.6226	0.7284
27	Huzhou	Zhejiang	11.1566	11.4120	6.3910	0.7294	0.7795	0.6562	0.7217
28	Shangyu	Zhejiang	11.3332	11.6174	6.0782	0.7410	0.7935	0.6241	0.7195
29	Fuyang	Zhejiang	11.2418	11.5371	6.0299	0.7350	0.7880	0.6191	0.7141
30	Danyang	Jiangsu	10.7756	11.2468	6.4096	0.7045	0.7682	0.6581	0.7103
31	Haimen	Jiangsu	10.6260	11.5524	6.2148	0.6947	0.7891	0.6381	0.7073
32	Changxing	Zhejiang	11.1287	11.3908	5.6487	0.7276	0.7780	0.5800	0.6952
33	Haining	Zhejiang	10.7715	11.0140	6.1221	0.7043	0.7523	0.6286	0.6950
34	Deqing	Zhejiang	11.1422	11.4009	5.4813	0.7285	0.7787	0.5628	0.6900
35	Rugao	Jiangsu	11.5364	10.0127	6.0661	0.7543	0.6839	0.6228	0.6870
36	Anji	Zhejiang	11.1433	11.4020	5.2477	0.7286	0.7788	0.5388	0.6821
37	Jiangdu	Jiangsu	10.6174	10.4218	6.1855	0.6942	0.7118	0.6351	0.6804
38	Yangzhong	Jiangsu	10.9469	11.0128	5.5093	0.7157	0.7522	0.5657	0.6779
39	Linan	Zhejiang	10.8715	10.7581	5.6618	0.7108	0.7348	0.5813	0.6756
40	Pinghu	Zhejiang	10.6386	10.3445	5.8305	0.6956	0.7066	0.5987	0.6669
41	Jintan	Jiangsu	10.2659	10.5169	5.7310	0.6712	0.7183	0.5884	0.6593
42	Liyang	Jiangsu	10.3685	9.9083	6.0513	0.6779	0.6768	0.6213	0.6587
43	Jiangyan	Jiangsu	10.2004	10.3037	5.7261	0.6669	0.7038	0.5879	0.6529
44	Ningguo	Anhui	11.1098	10.5026	4.8686	0.7264	0.7174	0.4999	0.6479
45	Jiashan	Zhejiang	10.4400	9.9688	5.6208	0.6826	0.6809	0.5771	0.6469
46	Xuancheng	Anhui	10.8784	10.4654	4.9940	0.7112	0.7148	0.5128	0.6463
47	Tongxiang	Zhejiang	10.1327	9.5474	6.0143	0.6625	0.6521	0.6175	0.6440
48	Jurong	Jiangsu	10.2375	10.0775	5.4934	0.6693	0.6883	0.5640	0.6406
49	Jingjiang	Jiangsu	9.9843	9.3874	6.0890	0.6528	0.6412	0.6252	0.6397
50	Yizheng	Jiangsu	10.2910	9.6193	5.6282	0.6728	0.6570	0.5779	0.6359
51	Guangde	Anhui	10.6053	10.4049	4.5985	0.6934	0.7107	0.4722	0.6254
52	Taixing	Jiangsu	9.3493	9.3926	6.0102	0.6113	0.6415	0.6171	0.6233
53	Langxi	Anhui	10.6485	10.4513	4.0502	0.6962	0.7139	0.4159	0.6086
54	Jingxian	Anhui	10.6349	10.4826	3.8459	0.6953	0.7160	0.3949	0.6021
55	Jixi	Anhui	10.6638	10.5192	3.5098	0.6972	0.7185	0.3604	0.5920
56	Jingde	Anhui	10.5921	10.3890	3.0131	0.6925	0.7096	0.3094	0.5705
57	Xiangshan	Anhui	12.6012	11.8307	0.0000	0.8239	0.8081	0.0000	0.5440
58	Xiuzhou	Zhejiang	10.4660	10.0123	0.0000	0.6843	0.6839	0.0000	0.4561
59	Xiucheng	Zhejiang	10.4371	9.9660	0.0000	0.6824	0.6807	0.0000	0.4544
60	Haiyan	Zhejiang	10.4282	9.9508	0.0000	0.6818	0.6797	0.0000	0.4538
61	Taicang	Jiangsu	0.0000	0.0000	6.5935	0.0000	0.0000	0.6770	0.2257
62	Lishui	Jiangsu	0.0000	0.0000	5.5221	0.0000	0.0000	0.5670	0.1890
63	Gaochun	Jiangsu	0.0000	0.0000	5.5104	0.0000	0.0000	0.5658	0.1886

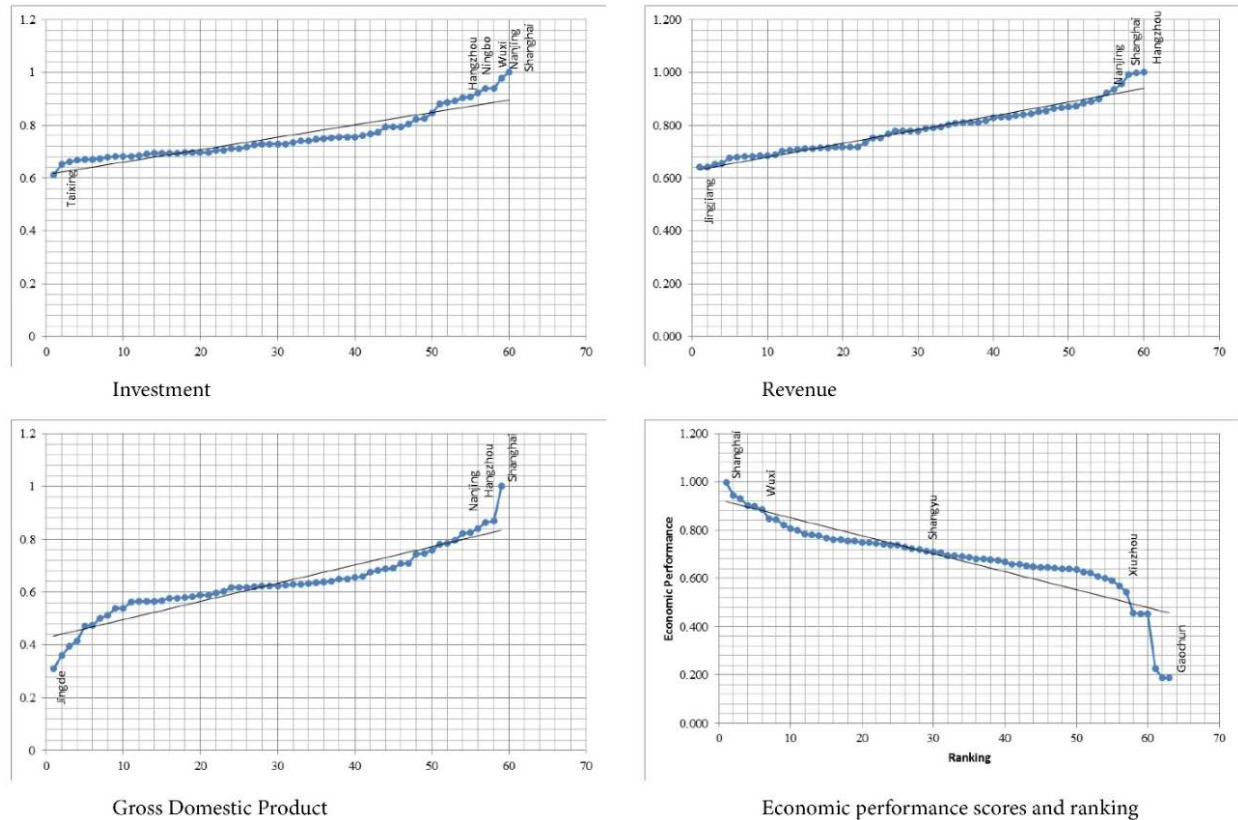


Figure 4. EPI composition: Investment, revenue, GDP, and economic performance indexes and rankings of 63 cities and towns in Changjiang Delta Region, 2010.

The distribution of normalized GDP, revenue, investment, and EPI were plotted in **Figure 4**. For GDP, the distribution of cities followed the trend line closely with Shanghai staying on top, as tier one, with some distance from the runner-up. With a few exceptions of cities falling behind, as in tier three, most of the cities were in the middle tier. This resembled the rank-size distribution of city size following Zipf's law of a stretched exponential distribution. While size, in terms of population, was one of the important characteristics of a city, there are other dimensions that also contribute to the definition and GDP is one of them. This implies that a well-thought out list of city dimensions could potentially form a stretched line of distribution of its own kind. For revenue, the distribution of cities followed more closely the trend line than GDP. A tripartite city arrangement was also reflected clearly in the plot, with Shanghai, Nanjing, and Hangzhou leading the rest of the cities by substantial margins. For investment, the distribution of cities also followed the trend line closely. The only obvious deviation occurred in the top five to six cities, regarded here as tier one, which exhibited a smaller positive margin than expected. The implication was that the cities and towns in the Changjiang Delta Region, in terms of economic performance, were following a hierarchical order. This order represented certain connections within the urban network, gravity of population, linkage of transit, and clustering of capital, to name a few. The EPI revealed that the economic power of the cities can be categorized into four tiers. The first tier included six cities: Shanghai, Nanjing, Hangzhou, Suzhou, Ningbo, and Wuxi with scores ranging from 0.887 to one with Shanghai outperforming the rest of the cities by a large margin. The second tier started with Changzhou at 8th place and ended around Shangyu at 28th place. The third tier was from 29th to 58th place, and the rest fell to the fourth tier. The scatter plot showed the relative relationship among the cities and towns, and was represented by rankings within the selected boundaries. If the networked region were to expand, then the normalization and scoring system should be reevaluated. Even though the absolute numbers of variables at certain years may stay the same, the relative position of those numbers may shift.

Moreover, it could help to better understand the networked region as a whole by comparing neighboring cities and towns, or urban networks.

In **Figure 5**, a well-performing urban network in the Changjiang Delta Region is depicted, based on the scenario that prioritizes disaster prevention and corridor development. The non-performing towns in terms of economic performance were represented with diagonal hatches. The development corridors, including both highway system and the rapid train system are shown in bold continuous lines, and the national roads in thinner lines. Fault lines in the region were also shown in wide continuous lines.

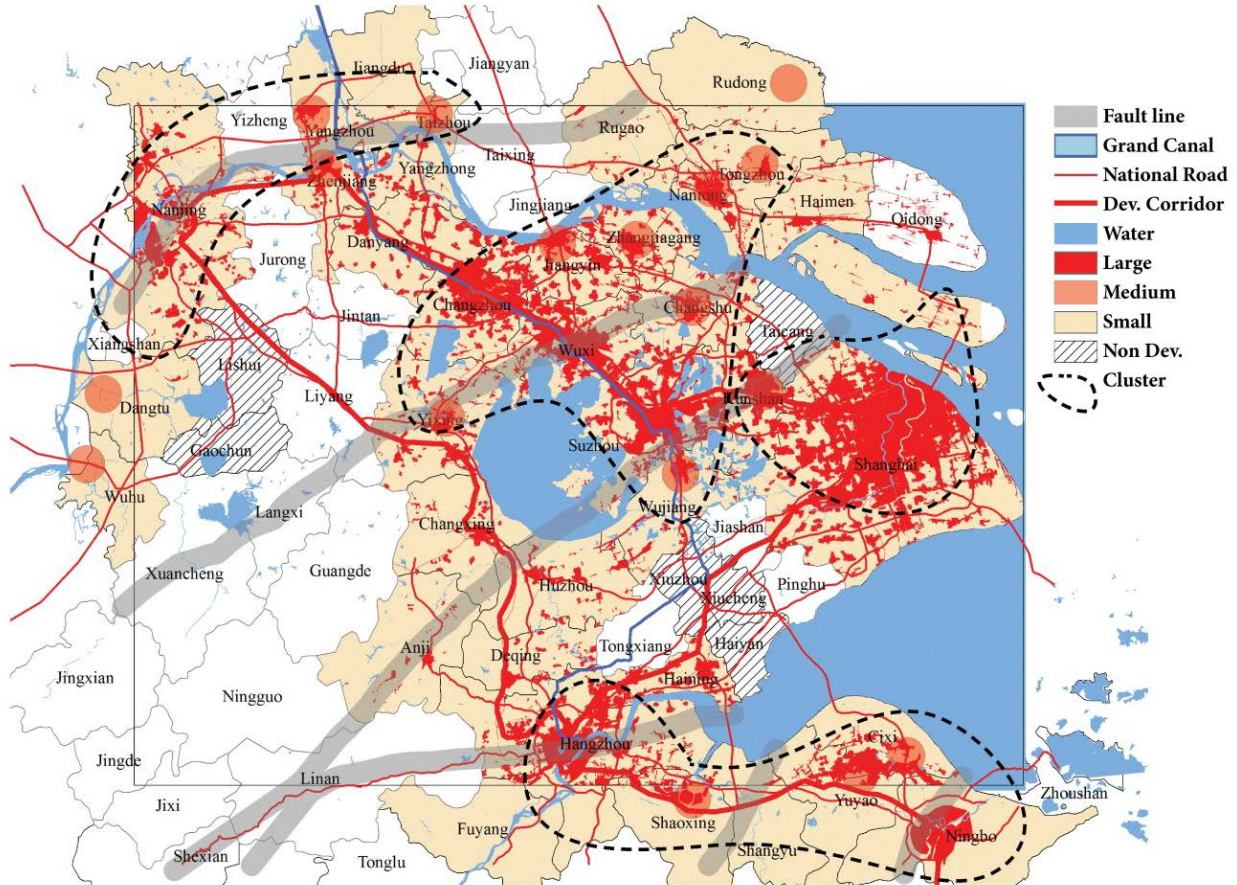


Figure 5. A well-performing urban network in the Changjiang Delta Region using scenario 4 disaster prevention of 2030 and EPI.

9. Conclusions

At the scale of a regional urban network, a single well-developed primate city, will likely not lead the network to its optimal condition. Similarly, a uniformly developed group of cities will not perform well together either. The question is how to make a well-performing urban network in the Changjiang Delta region and through what channel to make it meaningful?

Within the Changjiang Delta's regional urban network, four clusters of urban settlement appeared to be significant. First, the Shanghai metropolitan area, including satellite towns within the administrative boundary of Shanghai and also Kushan, a town that is located to the west of Shanghai and became part of the urban cluster as Shanghai expanded. This cluster is the economic engine for the entire region, if not for the whole nation. The potential urban growth is backed up with migrants from all parts of China and many foreign countries. The available land was also increased as Chongming Island, the second largest island of People's Republic of China, acquired road connections to Pudong to the south and Qidong to the north. The ongoing land reclamation also contributed to the supply of developable land area. Second,

there is the Suzhou-Changzhou-Nantong development triangle. This cluster is composed of many medium-sized cities with strong economies and dense peri-urban areas. In it, Suzhou, Wuxi, Changzhou, Jiangyin, Zhangjiagang, and Nantong are all well-integrated together with transportation networks as well as cultural linkages. To the east, the boundary between Suzhou and Kunshan was drawn along the fault line. To the Southwest, the cluster extended to Yixing, connecting to the Nanjing-Hangzhou rapid train corridor. To the north, the bridges between Nantong and Changshu, and Jiangyin and Subei weave these areas even closer than before. Rudong, was left out of the cluster because its remote location from the center of the area and the pull of Hai'an to the north. If the Shanghai metropolitan area is the 'dragon head', then this triangle cluster defines the distinct characteristic of the region. Third, there is the Nanjing-Zhenjiang-Yangzhou growth zone, which resembles the shape of the 'blue banana' of Europe but at a smaller scale. In this zone, the major urban development area sits on both sides the Changjiang. They are connected by seven cross-river bridges, which is one of the densest set of links for the entire river. Wuhu and Dangtu, both appeared in the map, were eliminated from the Nanjing-Zhenjiang-Yangzhou zone, because of their tighter connections with Hefei and other cities in Anhui Province to the west with the two cross-river bridges. Fourth, there is the Hangzhou-Shaoxing-Ningbo bay rim growth cluster. It marks the southern end of the Changjiang Delta Region, before the topography becomes hillier and geographical as well as culturally separate from southern Zhejiang Province. The outward connection of this cluster is more promising through the cross-bay bridges connecting Cixi and Shaoxing to the northern part of Zhejiang Province and Shanghai. One upshot of this outcome will be the parallel banding of urban networks largely perpendicular to the east-west growth corridors, in contrast to what seems to be conventional wisdom about the region's development.

In conclusion, a few factors stand out as important. First, the growth rate of each city and town and the balance among them comes to mind. Second, the development corridor between Nanjing and Hangzhou seems to be limited. The growth won't be as substantial as the Nanjing-Shanghai and Shanghai-Hangzhou corridors because of the small growth base, both in terms of economy and population. Third, comparisons among the scenarios provide instructive results with regard to unsuitable land development patterns.

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