An Empirical Model to Analyse the Economic Influences of Cities in Yangtze River Delta*

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Abstract

In this paper, based on a kind of gravity-type model imposed on the situation of city group, with which the different importance of various cities and the converted distance between pairs of cities involving traffic conditions are considered, a model to describe the economic influences of cities is proposed. This model can be used to explain some variation in regional development, such as the divergent and convergent phenomena. Also, this model shows the importance of transport means in economic relationship among cities. As an application, some impact analyses for the development of Yangtze River Delta are simulated.

1. Introduction

Concerning urban models, the gravity-type model is one of its main analytical foundations. The pioneer of this study attributes to Reilly, who established the Reilly's law of retail gravitation (1931) which states that 'A city will attract retail trade from a town in its surrounding territory, in direct proportion to the population size of the city and in inverse proportion to the square of the distance from the city'.[1)]

Following Reilly model, there are many developments in various areas. For instances, Casey (1955) and Huff (1963) improved it by using a probabilistic approach on the attractiveness of shopping centers; Lowry (1964) and Garin (1966) improved it by consisting of a series of equations for deriving and allocating land-use activities;[2)] Cordey-Hayes and Wilson (1971) improved it by introducing entropy maximizing approach to residential mobility.[3)]

In this study, following Casey's approach, the influence of cities, which include the different importance of various cities and the converted distance involving traffic conditions, will be improved. In

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** IDEC is an abbreviation of International Development and Cooperation.

1) In algebraic terms, the attraction of the shopping center of city i, R_i with population P_i, to individuals living in a site s, with distance d_{is} from city i, will be

$$R_i = P_i / d_{is}^2$$

2) See Mills' *Handbook of Regional and Urban Economics* (Vol. II), pp. 850–851.

3) See Nijkamp's *Handbook of Regional and Urban Economics* (Vol. I), pp. 111–112.

this way, an economic influence model of cities will be established, which can be used to analyse the interrelation of cities. The study can be considered as an improvement of Reilly model to the situation of city group.

The study object will be chosen as the Yangtze River Delta of China mainly because of the following two reasons: first, the developing tendency of Shanghai economy, which is the growth pole of Yangtze River Delta, is arousing wide interests in regional economics; secondly, this region is a special area of city group, where 51 various sizes of cities located on the land of 100,000 square km. In the application part of this paper, some impact analyses for the development of Yangtze River Delta will be simulated.

In section 2, through an empirical study for the expenditure flows among the cities in Yangtze River Delta, the influence of cities is discussed. And then, a partial city's influence model for commercial actions will be proposed. In section 3, a general economic influence model of cities will be proposed as a final result. As its applications, first, some variation in regional development, such as the divergent and convergent phenomena, will be explained; second, some impact analyses for the development of cities will be simulated. Section 4 will conclude the remarks of this paper.

2. Influence of a City

2-1 The Concepts

In order to improve Reilly model to the situation for describing the economic influence of cities, we start the study from Casey-Huff model (C-H model), which is usually used to describe the relationships of consumption expenditure among several shopping centers. The analysing process of C-H model is usually as follows:

First, the attractiveness for the residents of any zone i ($i=1, 2, \ldots, m$) from all the m shopping centers of zone j's ($j=1, 2, \ldots., m$) are:

$$F_1/d_{1i}^{\gamma},\ F_2/d_{2i}^{\gamma},\ \ldots,\ F_j/d_{ji}^{\gamma},\ \ldots,\ F_m/d_{mi}^{\gamma} \qquad (2.1)$$

where F_j is an attraction index of shopping center (e.g. floorspace) and d_{ji} are distances.

Secondly, based on above relationship, the probability that people from a residential zone go to a particular shopping center is:

$$\Pr\{\text{residents of zone i shopping in zone j}\} = (F_j/d_{ji}^{\gamma})/\Sigma_j (F_j/d_{ji}^{\gamma})$$

And, the flow of retail expenditure from each residential zone i ($i=1, 2, \ldots, m$) to each shopping center of zone j ($j=1, 2, \ldots, m$) is:

$$S_{ij}=C_i (F_j/d_{ji}^{\gamma})/\Sigma_j (F_j/d_{ji}^{\gamma}) \qquad (2.2)$$

where, C_i is the retail expenditure generated by the population of each residential zone i,

$$C_i=\textit{Population of zone } i \times \textit{Average retail expenditure per head} \qquad (2.3)$$

Thirdly, based on formula (2.2), the total retail sales S_j for shopping center j will be:

$$S_j=\Sigma_i [C_i (F_j/d_{ji}^{\gamma})/\Sigma_j (F_j/d_{ji}^{\gamma})] \qquad (2.4)$$

Usually, the retail sales S_j can also be obtained by observations, and the formula (2.4) can be used to calibrate the parameter γ.

However, C-H model cannot be used directly for the situation of city group, because it contains the implicit uniformity assumption of Reilly. Reconsidering the assumptions in C-H model, we can find that the model implicitly assumes that:

1) the expenditure of residents is uniform;
2) no difference on the importance of each center unless its size (floorspace);
3) the traffic conditions are similar.

All these assumptions are apparently not suitable to the situation of city group. In the following, the improvement in these directions will be discussed.

First, considering the expenditure of residents, formula (2.3), because the incomes in various cities are different, respective retail expenditure per head should be replaced. Furthermore, the difference between urban area and rural area should also be considered. In this way, the total consumption expenditure in a city can be estimated by:

$$C_i = E^U_i \times P^U_i + E^R_i \times P^R_i \tag{2.5}$$

where, E^U_i and E^R_i are consumption expenditures per capita in urban area and rural area of city i; P^U_i and P^R_i are urban population and rural population of city i.

Next, considering the importance of a city, if we limit our consideration just on economic factor, we can find GDP per capita in each city is rather important.[4] It is a natural thought that between a pair of cities, a city with higher GDP per capita is rather attractive. In this way, the ratio of GDP per capita, R_{ji}, is introduced as

$$R_{ji} = GDP_i / GDP_j \tag{2.6}$$

where GDP_i is the GDP per capita in city i. The attractiveness in C-H model (2.1) can be improved into:

$$F_1/(R_{1i}^{\alpha} d_{1i}^{\gamma}), \ldots, F_j/(R_{ji}^{\alpha} d_{ji}^{\gamma}), \ldots, F_m/(R_{mi}^{\alpha} d_{mi}^{\gamma}) \tag{2.7}$$

where F_j and d_{ji} are the same as before, α and γ are parameters.

At last, considering the traffic condition, there are various transport means to link each pair of cities: by bus, by train, or, by ship. The different transport means, of course, will have different effects on the flow of travelers. In this study, the main idea to consider this effect is to change the geographical distance into an abstract distance by multiplying a coefficient which is accordant to different traffic conditions: road (by bus), railway (by train) and, sea or river (by ship). Suppose that,

1. the road is chosen as the basis (namely, the coefficient of road is defined as 1);
2. for a certain distance, the people's willing to travel are mainly determined by the ratio of travel time and the ratio of fare;[5]
3. for any denoted distance, there is compensation for the both ratios around the distance.[6]

then, the relation between the both ratios in the coefficient should be a product; and, an average value of the both ratios should also be taken.[7] By noticing above compensation, it is convenient to choose the average value as a geometric one, namely,

$$\textit{coefficient} = \sqrt{\textit{ratio of time} \times \textit{ratio of fare}} \tag{2.8}$$

By multiplying the coefficient on the real distance d_{ji}, we can obtain a *converted distance* D_{ji}, in which the traffic condition between the two cities is considered.

Summarizing above discussion, as an improvement for C-H model, the attractiveness of the model can be reconsidered as:

$$F_1/(R_{1i}^{\alpha} D_{1i}^{\gamma}), \ldots, F_j/(R_{ji}^{\alpha} D_{ji}^{\gamma}), \ldots, F_m/(R_{mi}^{\alpha} D_{mi}^{\gamma}) \tag{2.9}$$

So that, the flow matrix of consumption expenditures can be estimated as:

$$S_{m\times m} = [C_i [F_j/(R_{ji}^{\alpha} D_{ji}^{\gamma})] / \Sigma_j [F_j/(R_{ji}^{\alpha} D_{ji}^{\gamma})]]_{m\times m} \tag{2.10}$$

Then, the total commercial sales S_j for city j can be calculated as

$$S_j = \Sigma_i \ [C_i [F_j/(R_{ji}^{\alpha} D_{ji}^{\gamma})] / \Sigma_j [F_j/(R_{ji}^{\alpha} D_{ji}^{\gamma})]] \tag{2.11}$$

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4) In the successive empirical study, we will find there is certain extent relationship between GDP per capita and the estimated errors of original C-H model.

5) So, the coefficient can be determined ty the ratio of travel time and that of fare which can be denoted as:
ratio of time (for means A) = *travel time* (by means A) / *time by bus*
ratio of fare (for means A) = *fare* (of means A) / *fare of bus*

6) That is, for an imaging transport means, if the ratio of time is τ (for example, $\tau = 1.1$), and the ratio of fare is $1/\tau$, then, people have the same willing to use this transport means as to use bus. Namely, in this situation we can say the coefficient of this transport means is 1.

7) For instance, if, for an imaging transport means, the ratio of time is τ (for example, $\tau = 0.9$), and the ratio of fare is τ also, that means, for a certain distance, people can cover the whole distance by this transport means but can only cover the $\tau \times 100\%$ of the distance by bus, then, it is better to define the coefficient as τ (the covered distance by this transport means over the covered distance by bus).

The last formula, as the same as it is in original C-H model, can be used to calibrate the parameter a and γ.

The main usefulness of the improved C-H model is that it can be used in the situation of city group.

2-2 An empirical evidence

In this sub-section, as an example of city group, we use the region of Yangtze River Delta to do an empirical study for the improved C-H model.

As the administrative system, the Yangtze River Delta is divided into 14 cities, including Shanghai (上海), seven cities of Jiangsu (江蘇) Province which are Suzhou (蘇州), Wuxi (無錫), Changzhou (常州), Nanjing (南京), Zhenjiang (鎮江), Yangzhou (揚州), Nantong (南通); and six cities of Zhejiang (浙江) Province which are Hangzhou (杭州), Jiaxing (嘉興), Huzhou (湖州), Shaoxing (紹興), Ningbo (寧波), Zhoushan (舟山). A simple map is illustrated in figure 2.1. The travel distances between each pair of cities, d_{ij}, are listed in table 2.1.[8] The distance d_{ii} are calculated based on the estimation of the number of shopping center in each city, divided into urban area and rural area (see Appendix).

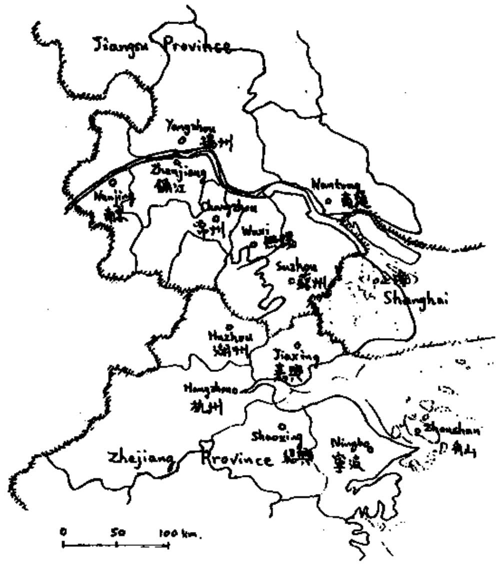

Figure 2.1 The Cities of Yangtze River Delta

By statistical yearbooks, the indices of the 14 cities for C-H model can be obtained, which are listed in table 2.2. Using the process of formulas (2.1)-(2.4), and by the principle of minimizing the sum of absolute errors, an estimation for the flow of consumer expenditure among the 14 cities can be obtained, while the calibrated parameter γ is 2.0.[9]

Table 2.1 The Distances (d_{ij}) between each Pair of Cities (unit: kilometer)

		Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)
1.	Shanghai	0.80	84	126	165	303	238	282	128	201	110	162	261	259	250
2.	Suzhou	84	1.63	42	81	219	154	200	168	162	71	98	222	330	334
3.	Wuxi	126	42	1.46	39	177	112	158	126	204	113	129	264	372	376
4.	Changzhou	165	81	39	1.64	138	73	159	127	217	152	127	277	385	415
5.	Nanjing	303	219	177	138	1.45	65	103	293	327	290	237	387	495	553
6.	Zhenjiang	238	154	112	73	65	1.72	30	200	290	225	200	350	458	488
7.	Yangzhou	282	200	158	159	103	30	1.89	190	362	271	286	422	530	532
8.	Nantong	128	168	126	127	293	200	190	1.62	330	239	255	390	498	370
9.	Hangzhou	201	162	204	217	327	290	362	330	1.64	91	90	60	168	248
10.	Jiaxing	110	71	113	162	290	225	271	239	91	1.31	91	151	259	339
11.	Huzhou	162	98	129	127	237	200	286	255	90	91	1.79	150	258	338
12.	Shaoxing	261	222	264	277	387	350	422	390	60	151	150	1.43	108	188
13.	Ningbo	259	230	372	385	495	458	530	498	168	259	258	108	1.45	80
14.	Zhoushan	250	334	376	415	553	488	532	370	248	339	338	188	80	1.04

8) The direct railway, road or waterway which connects a pair of cities is chosen as the distance between the both cities, while the priority is given in the order of railway, road, waterway.

9) In this calibration, we have following sums of absolute error for various parameter γ:

γ	1.7	1.8	1.9	2.0	2.1	2.2	2.3
Sum(|error|)	2.303	2.267	2.212	2.142	2.158	2.236	2.307

Therefore, we have:

$$\mathrm{Min}\{\mathrm{Sum}(|\mathrm{error}|)\}=2.142, \quad \text{while } \gamma=2.0.$$

In this estimation, the estimated errors for various cities are listed in table 2.3, while the second row are the GDP per capita in various cities. Moreover, the correlation coefficient for the two variables is −0.437. It shows that the difference of GDP per capita is an important factor to the flow of consumer expenditure in city group.

According to the improved C-H model, the flows of consumer expenditure can be reanalysed. First, based on formula (2.6), the ratio of GDP per capita for each pair of cities can be obtained as table 2.4. Secondly, in order to obtain the converted distance, the coefficient for railway is calculated to be 0.6, and the coefficient for waterway is calculated to be 1.5,[10] while the coefficient for road is defined as 1.0. In this way, involving the different traffic conditions, we can calculate the ***converted distance*** among the 14 cities which are listed in table 2.5.

Table 2.2 The Indices of the 14 Cities for Casey-Huff Model

Cities	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)	Total
F_j	769328	208029	184516	115063	206524	86893	223520	173228	234546	116722	89017	147182	231398	36205	
C_i	67747	16512	13326	9537	16666	6730	17395	20855	22666	10181	7367	12799	19989	4001	245773
S_j	75559	19828	17298	10698	18219	5559	13900	13894	20533	12368	7346	9626	19133	2815	245773

Notes: 1) The data sources are *'96 Statistical Yearbook of Shanghai, '96 Statistical Yearbook of Jiangsur,* and, *'96 Statistical Yearbook of Zhejiang.*

2) F_j is the employee of retail sales & catering in city j (unit: person);

3) C_i is the consumer expenditure in city i (unit: million *yuan*);

4) S_j is the retail sales in city j (unit: million *yuan*).

Table 2.3 The Estimated Errors and GDP Per Capita in the 14 Cities

Cities	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)	Sum(|errer|)
Estimated errors	0.018	-0.182	-0.206	-0.224	-0.024	-0.008	0.257	0.335	0.087	-0.269	-0.206	0.259	0.053	-0.013	2.142
GDP per capita	18943	15764	17734	11080	11049	10858	6445	5945	12743	9843	8998	9682	11578	7478	

Note: The sources of GDP per capita are *'96 Statistical Yearbook of Shanghai, '96 Statistical Yearbook of Jiangsur,* and, *'96 Statistical Yearbook of Zhejiang.* The unit is *yuan.*

Table 2.4 The Ratio of GDP (R_{ji}) for Each Pair of Cities in Yangtze River Delta

Objective Cities \ Cities	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)
GDP$_j$	*18943*	*15764*	*17734*	*11080*	*11049*	*10858*	*6445*	*5949*	*12743*	*9843*	*8998*	*9682*	*11578*	*7478*
1. Shanghai	1.000	1.202	1.068	1.710	1.714	1.745	2.939	3.184	1.487	1.925	2.105	1.957	1.636	2.533
2. Suzhou	0.832	1.000	0.889	1.423	1.427	1.452	2.446	2.650	1.237	1.602	1.752	1.628	1.362	2.108
3. Wuxi	0.936	1.125	1.000	1.601	1.605	1.633	2.752	2.981	1.392	1.802	1.971	1.832	1.532	2.371
4. Changzhou	0.585	0.703	0.625	1.000	1.003	1.020	1.719	1.862	0.869	1.126	1.231	1.144	0.957	1.482
5. Nanjing	0.583	0.701	0.623	0.997	1.000	1.018	1.714	1.857	0.867	1.123	1.228	1.141	0.954	1.478
6. Zhenjiang	0.573	0.689	0.612	0.980	0.983	1.000	1.685	1.825	0.852	1.103	1.207	1.121	0.938	1.452
7. Yangzhou	0.340	0.409	0.363	0.582	0.583	0.594	1.000	1.083	0.506	0.655	0.716	0.666	0.557	0.862
8. Nantong	0.314	0.377	0.335	0.537	0.538	0.548	0.923	1.000	0.467	0.604	0.661	0.614	0.514	0.796
9. Hangzhou	0.673	0.808	0.719	1.150	1.153	1.174	1.977	2.142	1.000	1.295	1.416	1.316	1.101	1.704
10. Jiaxing	0.520	0.624	0.555	0.888	0.891	0.907	1.527	1.655	0.772	1.000	1.094	1.017	0.850	1.316
11. Huzhou	0.475	0.571	0.507	0.812	0.814	0.829	1.396	1.513	0.706	0.914	1.000	0.929	0.777	1.203
12. Shaoxing	0.511	0.614	0.546	0.874	0.876	0.892	1.502	1.628	0.760	0.984	1.076	1.000	0.836	1.295
13. Ningbo	0.611	0.734	0.653	1.045	1.048	1.066	1.796	1.946	0.909	1.176	1.287	1.196	1.000	1.548
14. Zhoushan	0.395	0.474	0.422	0.675	0.677	0.689	1.160	1.257	0.587	0.760	0.831	0.772	0.646	1.000

10) According to the investigation from *Shanghai Bus Center, Shanghai Railway Station* and *Shanghai Travel Ship Company,* both the *ratio of time* for train or for ship and the *ratio of fare* for train or for ship can be calculated based on average observations. By formula (2.8), both coefficients can be calculated.

By using F_j, C_i and S_j in table 2.2, R_{ji} in table 2.4, D_{ji} in table 2.5, the improved C-H model can be applied to Yangtze River Delta. According to the principle of minimizing the sum of absolute errors, parameters $\alpha=4.7$, $\gamma=2.6$ are calibrated.[11] The errors of each term in the estimate are listed in the table 2.6. Since the sum of absolute errors has decreased from 2.142 to 1.713, it can be considered that there is a real improvement in the new model. Furthermore, in this situation, the correlation coefficient between the estimated error and the GDP per capita equals 0.143,[12] which shows that the improved model also reflects the different importance of various cities indeed. This result gives an evidence that the commercial attractiveness of city j to city i has the form of:

$$A_{ji}=F_j/(R_{ji}^{\alpha}\,D_{ji}^{\gamma}) \tag{2.12}$$

where F_j is total floorspace of city j; R_{ji} equals GDP per capita of city i over that of city j; D_{ji}^{γ} is a converted distance between cities j and i involving traffic condition; α and γ are parameters.

Table 2.5 The Converted Distances (D_{ji}) between Each Pair of Cities (unit: kilometer)

	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)
1. Shanghai	0.80	50	76	99	182	143	282	192	121	66	162	157	388	375
2. Suzhou	50	1.63	25	49	131	92	200	168	162	71	98	222	330	425
3. Wuxi	76	25	1.46	23	106	67	158	126	204	113	129	264	372	451
4. Changzhou	99	49	23	1.64	83	44	159	127	217	152	127	277	385	474
5. Nanjing	182	131	106	83	1.45	39	103	293	327	290	237	387	495	557
6. Zhenjiang	143	92	67	44	39	1.72	30	200	290	225	200	350	458	518
7. Yangzhou	282	200	158	159	103	30	1.89	190	362	271	286	422	530	657
8. Nantong	192	168	126	127	293	200	190	1.62	330	239	255	390	498	567
9. Hangzhou	121	162	204	217	327	290	362	330	1.64	55	90	36	101	221
10. Jiaxing	66	71	113	152	290	225	271	239	55	1.31	91	91	155	275
11. Huzhou	162	98	129	127	237	200	286	255	90	91	1.79	150	258	378
12. Shaoxing	157	222	264	277	387	350	422	390	36	91	150	1.43	65	185
13. Ningbo	388	330	372	385	495	458	530	498	101	155	258	65	1.42	120
14. Zhoushan	375	425	451	474	557	518	657	567	221	275	378	185	120	1.04

Table 2.6 The Errors of Improved C-H Model

Cities	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)	Sum(|error|)
Retail Sales (1)	75559	19828	17298	10698	17218	5559	13900	13894	20533	12368	7346	9626	19133	2815	
Difference (2)	7746	-2169	36	-3504	−799	92	−152	980	2404	-4848	-2275	1326	1129	33	
Error (3)=(2)/(1)	0.103	-0.109	0.002	-0.328	-0.046	0.017	-0.011	0.071	0.117	-0.392	-0.310	0.138	0.059	0.012	1.713

Note: Row (2)=estimated sales (by improved C-H model)−real sales (1).

11) The sums of absolute errors in the estimation for some various parameters are listed as follows:

$\gamma\backslash\alpha$	4.4	4.5	4.6	4.7	4.8	4.9	5.0
2.4	1.959	2.020	2.081	2.143	2.206	2.269	2.333
2.5	1.750	1.778	1.805	1.833	1.880	1.939	2.000
2.6	1.767	1.741	1.719	1.713	1.717	1.734	1.756
2.7	1.893	1.871	1.848	1.824	1.799	1.774	1.749
2.8	2.002	1.983	1.963	1.943	1.922	1.900	1.878

In this way, we get:

$$\mathrm{Min}|\mathrm{Sum}(|\mathrm{error}|)|=1.713, \quad \text{while } \alpha=4.7,\ \gamma=2.6.$$

12) Because the errors and GDP per capita are as what listed as follows:

Cities	Shanghai	Suzhou	Wuxi	Changzhou	Nanjing	Zhenjiang	Yangzhou	Nantong	Hangzhou	Jiaxing	Huzhou	Shaoxing	Ningbo	Zhoushan
Estimated errors	0.103	-0.109	0.002	-0.328	-0.046	0.017	-0.011	0.071	0.117	-0.392	-0.310	0.138	0.059	0.012
GDP per capita	18943	15764	17734	11080	11049	10858	6445	5945	12743	9843	8998	9682	11578	7478

we can get the estimator of the correlation coefficient for the two variables is 0.143.

2-3 Force-sphere model for commercial and service activities

In the previous sub-section, we have obtained the commercial attractiveness of city j to city i (formula 2.12). In order to compare commercial influences of various cities, let's consider the attractiveness of unit floorspace in them.

According to (2.12), the attractiveness of unit floorspace in city j to city i is:

$$A^0_{ji}=1/(R_{ji}^{\alpha}\,D_{ji}^{\gamma}) \qquad (2.13)$$

Its attractiveness of unit floorspace to all cities can be represented as a column vector:

$$A^0_j=[1/(R_{j1}^{\alpha}\,D_{j1}^{\gamma}),\ \ldots,\ 1/(R_{ji}^{\alpha}\,D_{ji}^{\gamma}),\ \ldots,\ 1/(R_{jm}^{\alpha}\,D_{jm}^{\gamma}\,]' \qquad (2.14)$$

that is:

$$A^0_j=(1/\{(GDP_1/GDP_j)^{\alpha}\,D_{j1}^{\gamma}\},\ \ldots,\ 1/\{(GDP_i/GDP_j)^{\alpha}\,D_{ji}^{\gamma}\},\ \ldots,\ 1/\{(GDP_m/GDP_j)^{\alpha}\,D_{jm}^{\gamma}\})' \qquad (2.15)$$

However, because of the difference of GDP_i, it is very difficult to find a continuous function of distance like the form of Reilly model. For the purpose of deciding such kind of continuous function, we try to use the average GDP per capita to replace the GDP_i's in above attractiveness. Namely, now, the attractiveness is:

$$F_1/(R_1^{\alpha}\,D_{1i}^{\gamma}),\ \ldots,\ F_j/(R_j^{\alpha}\,D_{ji}^{\gamma}),\ \ldots,\ F_m/(R_m^{\alpha}\,D_{mi}^{\gamma}) \qquad (2.16)$$

where: R_j=average GDP per capita/GDP_j;[13] F_j, D_{ji}, α and γ are the same as the previous.

By using F_j, C_i and S_j in table 2.2, D_{ji} in table 2.5, R_j defined as above, as the same process as it is used previously, parameters $\alpha=4.7$, $\gamma=2.6$ are calibrated.[14] The errors of each term in the estimation are listed in the table 2.7. Comparing with previous discussion, there is almost no change by using R_j instead of R_{ji}.

In this way, we can get a continuous function to represent the attractiveness of unit floorspace in city j to any site z, with travel distance d_{jz}, as.

$$A^0_{jz}=1/(R_j^{\alpha}\,D_{jz}^{\gamma}) =1/\{(GDP\text{-}av/GDP_j)^{\alpha}\times D_{jz}^{\gamma}\} \qquad (2.17)$$

Then, the commercial influence of city j to any site z can be represented as:

Table 2.7 The Errors of Further Improved C-H Model (unit: million *yuan*)

Cities	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)	Sum(|error|)
Retail Sales (1)	75559	19828	17298	10698	17218	5559	13900	13894	20533	12368	7346	9626	19133	2815	
Difference (2)	7746	-2169	36	-3504	-799	92	-152	980	2404	-4848	-2275	1326	1129	33	
Error (3)=(2)/(1)	0.103	-0.109	0.002	-0.328	-0.046	0.017	-0.011	0.071	0.117	-0.392	-0.310	0.138	0.059	0.012	1.713

Note: Row (2)=estimated sales (by improved C-H model)−real sales (1).

13) In our study case, the ratios are as follows:

Cities	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)	Average
GDP_j (*yuan*)	18923	15764	17734	11080	11049	10858	6445	5949	12743	9843	8998	9682	11578	7478	11985.5
R_j	0.633	0.760	0.676	1.082	1.085	1.104	1.860	2.015	0.941	1.218	1.332	1.238	1.035	1.603	

Where R_j is defined as GDP-av/GDP_j, while GDP-av is the average GDP per capita, namely, 11985.5.

14) The sums of absolute errors in the estimation for some various parameters are listed as follows:

$\gamma\backslash\alpha$	4.4	4.5	4.6	4.7	4.8	4.9	5.0
2.4	1.959	2.020	2.081	2.143	2.206	2.269	2.333
2.5	1.750	1.778	1.805	1.833	1.880	1.939	2.000
2.6	1.767	1.741	1.719	1.713	1.717	1.734	1.756
2.7	1.893	1.871	1.848	1.824	1.799	1.774	1.749
2.8	2.002	1.983	1.963	1.943	1.922	1.900	1.878

In this way, we get:

$$\mathrm{Min}\{\mathrm{Sum}(|\mathrm{error}|)\}=1.713, \quad \text{while } \alpha=4.7,\ \gamma=2.6.$$

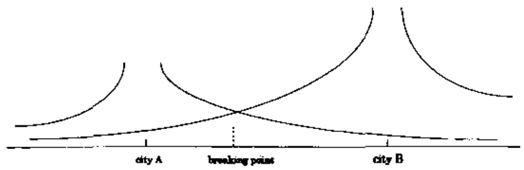

Figure 2.2 An Illustration for the Influence A_{jz} of Two Cities

$$A_{jz}=F_j/(R_j^{\alpha}\,D_{jz}^{\gamma})$$
$$=F_j/\{(GDP\text{-}av/GDP_j)^{\alpha}\times D_{jz}^{\gamma}\} \qquad (2.18)$$

The relationship of the influence A_{jz} for various cities can be illustrated as figure 2.2, where two cities are taken as an example.

The trace of breaking points between two cities, for ordinary distance, forms a circle around the city with smaller influence.[15] Furthermore, the breaking point curves of three cities will across at one point, such as it is illustrated as figure 2.3.[16] That is what we call it as the *force-sphere model for commercial and service actions*. In this way, the concept of Reilly's breaking point has been improved to multi-cities system, where the *breaking edge curve* (namely, the trace of breaking points) of a city is a combination of pieces of circles.

In above discussions, we have got a partial influence model of a city which is limited in commercial and service activities, that is the *force-sphere model for commercial and service activities*. This model can be used to analyse the commercial influence of cities (that is, the *force sphere* of cities) in the case of city group.

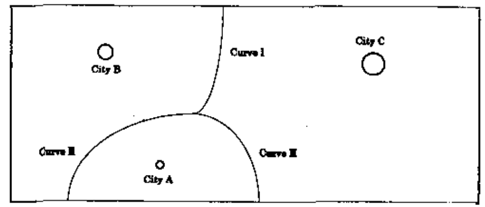

Figure 2.3 An Illustration of the Crossing Point of Breaking Edge Curves among Three Cities

3. A General Influence Model

3–1 The economic influence model for cities

In order to consider the economic relationships among the cities, we try to find a comprehensive economic influence model of a city to its surroundings. As a natural idea, a comprehensive influence force of cities can be illustrated as figure 3.1. And, the function form of curves in figure 3.1 can be represented as:

$$\frac{\text{a function of the } \textit{city's function}}{\text{a function of the } \textit{distance, etc.}} \qquad (3.1)$$

If we assume that the comprehensive influence force of a city has a similar structure to the commercial influence, the attractiveness of unit floor-space in the city (2.17) can be used to replace the denominator of the formula (3.1). By considering the numerator of the formula (3.1), the influence of a city is not limited in its commercial actions. There

15) For ordinary distance, the influence of city j as formula (3.6) is:

$$A_{jz}=F_j/\{(GDP\text{-}av/GDP_j)^{\alpha}\times d_{bz}^{\gamma}\}$$

Based on Reilly's definition, the influence of two cities A and B are equal at a breaking point, that is,

$$F_a/\{(GDP\text{-}av/GDP_a)^{\alpha}\times d_{az}^{\gamma}\}=F_b/\{(GDP\text{-}av/GDP_b)^{\alpha}\times d_{bz}^{\gamma}\}$$

If we assume there is a coordinate axis on the system when the coordinate of city A is (0, 0) and that of city B is (d, 0), let z, with coordinate (x, y), is a breaking point in the system, then we have

$$d_{az}=x^2+y^2;\quad \text{and}\quad d_{bz}=(x-d)^2+y^2$$

Because F_a, F_b, GDP_a, GDP_b, α and γ are constants, above equation can be represented as:

$$d_{az}^{2}/d_{bz}^{2}=\{x^2+y^2\}/\{(x-d)^2+y^2\}=C;\quad C=\{(F_a/F_b)(GDP_a/GDP_b)^{\alpha}\}^{2/\gamma}=\text{Constant}>0$$

By this equation, we get follows:

$$\{x-Cd/(C-1)\}^2+y^2=Cd^2/(C-1)^2$$

In this way, the trace of the breaking point construct a circle, which is around the city which have smaller influence. The location of the circle center is $Cd/(C-1)$; and, the radius is $C^{1/2}d/|C-1|$.

16) The reason is that there is $A_b=A_c$ on curve I; there is $A_a=A_b$ on curve II; and, there is $A_c=A_a$ on curve III. Then, it must be $A_a=A_b=A_c$ at the crossing point, which is an unique point.

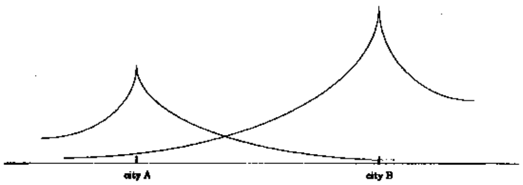

Figure 3.1 An Illustration of Comprehensive Influences of cities

are some other factors, such as the developing level of industry, the advanced grade of culture and science, and the quality of public treatment. In this way, there may be some indices (var^k) to reflect city's influence.[17] For example, the ratio of doctors (in hospitals) in a city, denoted as Rd in the following, may be used to represent the quality of public treatment; just as the ratio of employees of retail sales and service centers in a city, denoted as Rr in the following, can be used to represent the developing level of a city's commercial activities. Since the correlation coefficient between the ratio of doctors and the influence force is 0.426,[18] it shows that there is a certain relationship between them.

Because of the data limited, we can not discuss various variables in detailed. However, if we assume that such kind of indices can be determined by using the method of regression analysis, we can establish an *economic influence model for cities*. The economic influence of city j to a site z, INF_{jz}, is:

$$INF_{jz}=f(P_j, var^1_j, \ldots, var^n_j)/(R_j^{\alpha} D_{jz}^{\gamma}) \qquad (3.2)$$

where f is a positively relative function; P_j is the population of city j; var^k_j is a development index k of city j; R_j equals to average GDP per capita over GDP per capita in city j; D_{jz} is a converted distance involving traffic condition; α and γ are parameters.

As a partial form of this model, a simple influence model can be represented, as an example, as:[19]

$$INF_{jz}=f(P_j, Rd_j, Rr_j)/(R_j^{\alpha} D_{jz}^{\gamma}) \qquad (3.3)$$

where Rd_j and Rr_j are the ratios explained above.

3-2 Simulating some effects in regional development

First, based on the *economic influence model* (3.2), if other conditions are fixed, some influence factor in city B improves, such as GDP increase, population increase, the living condition or the public treatment improvement, will result to an increase of the total influence of this city to other cities. This effect can be illustrated as figure 3.2.

Secondly, in two-cities system, if there is a special impact occurred in a city, city j, while the conditions in another city are assumed to keep un-

17) In theoretical sense, if statistical data are available, these indices should be included in regression analyses.

18) It is calculated according to following data:

Cities	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)
Ratio of doctor	4.130	2.125	2.150	2.120	3.140	2.029	2.160	2.372	2.718	1.461	1.451	1.357	1.656	1.907
Influence of city	7811	3315	3971	1161	552	-1171	-3496	-6961	-2134	2188	-21	-3174	-856	-1186

Notes: 1) Ratio of doctor is the number of doctors in per thousand residents;
2) Influence of city is the difference of sales and expenditures in each city.

19) If we denote Rd'_j to be the rate of Rd_j to average ratio of doctors in this region, Rd-av, namely, $Rd'_j=Rd_j/Rd\text{-}av$; and so is Rr'_j; then, referring the form of Reilly model, one of possible forms of formula (3.3) will be:

$$INF_{jz}=P_j^{a\,Rd'_j+b\,Rr'_j}/(R_j^{\alpha} D_{jz}^{\gamma})$$

where a and b are parameters which are positive.

For this concrete model, if we assume:

a. the GDP in all cities in this region are same, that is $GDP_j \equiv GDP\text{-}av$;
b. the developed level of each city in this region are equal, that is $Rd'_j \equiv Rr'_j \equiv 1$;
c. the traffic conditions in all the region are same, that is $D_{jz}=d_{jz}$;
d. furthermore, we assume $a+b=1$, and $\gamma=2$.

then, this model will just be Reilly model:

$$INF_{jz}=P_j/d_{jz}^2$$

That is to say, Reilly model is just a special case if the difference among various cities is ignored.

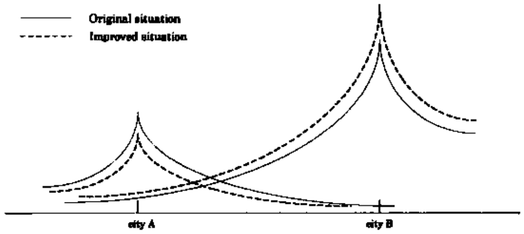

Figure 3.2 The Effects of the Development of City B

changed, it will result to the following process:[20)]

$$\text{GDP of city } j\uparrow \Rightarrow \text{GDP-av}/\text{GDP}_j\downarrow \Rightarrow \text{INF}_j\uparrow \Rightarrow \text{P}_j\uparrow \text{ (especially, } \text{var}^k_j\uparrow\text{)}$$

This result shows that, under a natural condition, the regional economic development is divergent.

Thirdly, if other conditions keep unchanged, the traffic condition from city j to the site s is improved, then, the economic influence of city j to site s will increase. So, if the traffic condition between two cities, city A and B, is improved, the inter-influence between these two cities will be increased at the same time. This phenomenon can be illustrated as figure 3.3. This result shows that, the improvement of traffic condition between developed areas and some developing cities will become a convergent factor for the economic development in those developing cities.

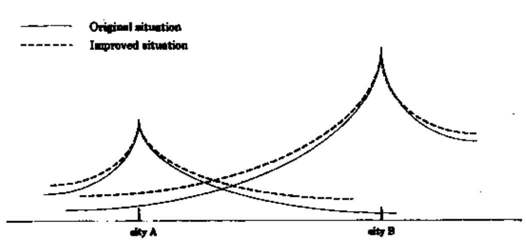

Figure 3.3 The Effects of the Improvement of Traffic Conditions between Two Cities

3-3 Impact analyses in Yangtze River Delta

As an application of above model, let's consider some impact analyses for the cities in Yangtze River Delta.

In general, the indices in ***economic influence model*** (3.2) can be selected by regression method. Referring the form of Reilly Model, one of possible forms, taking the partial model (3.3) as an example, will be:

$$\text{INF}_{jz} = \frac{P_j^{\,a\,Rd'_j + b\,Rr'_j}}{\{(\text{GDP-av}/\text{GDP}_j)^{\alpha} \times D_{jz}^{\,\gamma}\}} \qquad (3.4)$$

where a and b are parameters which are positive; Rd'_j is the rate of Rd_j to average ratio of doctors in this region, Rd-av, namely, $Rd'_j = Rd_j/\text{Rd-av}$; and so is Rr'_j.

Based on that result, a concrete functional model can be calibrated. However, because of data limitation, here we can only show some descriptive impact analyses. Referring Reilly model, we assume the parameters as: $\gamma=2$; $\alpha=1$; $a=0.5$ and $b=0.5$. Under above assumption, the model (3.4) can be denoted as:

$$\text{INF}_{jz} = \frac{P_j^{\,(Rd'_j + Rr'_j)/2}}{\{(\text{GDP-av}/\text{GDP}_j) \times D_{jz}^{\,2}\}} \qquad (3.5)$$

Based on this concrete model, some impact analyses can be done. If we denote $\text{INF}_{jz} = \text{Inf}_j / D_{jz}^2$, the present value of influences, INF_{jz}, can be calculated as Inf_j listed in table 3.1.

Now, let's consider that under the condition of rapid development of Pudong (浦東) economy, an important regional policy is how to provide the city's economic influence in Yangtze River Delta. In order to simplify our discussion, we assume that the variation of residents in each city is neglected. In the following discussion, we assume that the basic annual growth rate of GDP in each city will be

20) Notice that $\text{INF}_j\uparrow$ will result to $P_j\uparrow$, and, among this process, the ratio of persons with some technique will increase fast, that means, $\text{var}^k_j\uparrow$ $(k=1, \ldots, n)$.

Table 3.1 The Influence of Each City as Present Situation[21)]

City	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)
Inf_i	95.81	6.33	6.28	2.65	6.13	2.04	2.84	2.39	7.04	2.02	1.51	2.30	4.35	0.61

Table 3.2 An Estimation of GDPs in 2005, without Considering Pudong's Development (unit: million *yuan*)

City	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)
GDP 1995	246257	90311	76111	36970	57646	28586	60502	46653	76201	32127	22731	41121	60926	7349
GDP 2005	632944	232123	195626	95022	148165	73474	155506	119910	195856	82575	58425	105692	156596	18889

9.9%.[22)] Then, if the influence of Pudong's development is not involved, an estimation of the GDP of each city in ten years, the year 2005, may be estimated as what is listed in table 3.2. Since the total investment to Pudong area can be estimated as 44,000 million yuan a year in a few years,[23)] for simplicity, we assume that the investment to Pudong area can cause an additional GDP's increase of 20,000 million *yuan* a year continuously. Then, till the year 2005, the total investment to Pudong area can cause the additional GDP's increase of 200,000 million *yuan* a year. Now we show three cases, which assumes the different influences of this GDP's increase on various cities based on different regional policies.

Case 1: If the policies of prior to developing Shanghai economy is adopted, while other cities are not paid much attention, then, the additional GDP will mainly take place in Shanghai, assuming that is 80%, namely 160,000 million *yuan* of the total additional GDP. The remainder, for the purpose of simplicity, is assumed that they take place uniformly in other 13 cities, that is 3077 million *yuan* for each city. Under this assumption, the variations of GDPs and city's influences in the year 2005 are estimated as what are listed in table 3.3.

From table 3.3 we can see that in this case the city influence of Shanghai will increase largely while those of other cities will decrease. The regional disparity will be enlarged. If the residents removes

Table 3.3 The Variations of GDPs and City's Influences (Case 1)

City	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)
Sumed GDP (mil. *yuan*)	792944	235200	198703	98099	151242	76551	158583	122987	198933	85652	61502	108769	159673	21966
GDP per capita (*yuan*)	60932	41054	46297	29402	28989	29077	16892	15682	33269	26242	24345	25611	30344	22350
City influence	110.31	5.90	5.86	2.52	5.75	1.95	2.67	2.26	6.57	1.92	1.46	2.18	4.08	0.66
Influ. without impact	95.81	6.33	6.28	2.65	6.13	2.04	2.84	2.39	7.04	2.02	1.51	2.30	4.35	0.61
Increased rate	15%	-7%	-7%	-5%	-6%	-4%	-6%	-6%	-7%	-5%	-3%	-5%	-6%	7%

Note: Increased rate = (City influence − Influ. without impact)/Influ. without impact

21) The respective statistical data are as follows:

City	Shanghai	Suzhou	Wuxi	Changzhou	Nanjing	Zhenjiang	Yangzhou	Nantong	Hangzbou	Jiaxing	Huzhou	Shaoxing	Ningbo	Zhoushan
Popula.	13.01	5.73	4.29	3.34	5.22	2.63	9.39	7.84	5.98	3.26	2.53	4.25	5.26	0.98
Rd'	1.66	0.85	0.86	0.85	1.26	0.81	0.87	0.95	1.09	0.59	0.58	0.54	0.66	0.76
Rr'	1.54	0.95	1.12	0.90	1.03	0.86	0.62	0.58	1.02	0.93	0.92	0.91	1.15	0.96
GDP_j	18923	15764	17734	11080	11049	10858	6445	5949	12743	9843	8998	9682	11578	7478

22) According to *'96 China Statistical Yearbook* (page 23), the average annual growth rate of GDP (1986–1995) in the nation is 9.9%.

23) According to *'96 Statistical Yearbook of Shanghai,* the main state investment to Pudong area in 1995 is 29,082 million *yuan*; the direct foreign investments through contracts agreements accumulated at year-end of 1995 is about 73,165 million *yuan*. Assuming that the state investment will keep a similar level, and the direct foreign investments will continue to input about one fifth of above value each year, the total investment is 44,000 million *yuan* a year.

are involved, by formula (3.5), the regional disparity will become further larger.

Case 2: If the regional policy is that not only the development of Shanghai economy is considered, but also the advantage of exploring Pudong area is used to spur the whole economic development of the cities in Yangtze River Delta. For example, production processes can be transferred to these cities instead of remaining them in Shanghai. Then, the additional GDP will take place throughout this region. For the purpose of simplicity, we assume that the 400,000 million *yuan*'s GDP takes place uniformly in these 14 cities, that is 14,286 million *yuan* in each city. Under such assumption, the variations of GDPs and city's influences in the year 2005 are estimated as what are listed in table 3.4.

From table 3.4 we can see that in this case the city influence of many cities will increase and the regional disparity will be reduced. If the resident moves are involved, by formula (3.5), the regional disparity will become further reduced.

Case 3: Furthermore, if the traffic conditions between pairs of cities are improved, the inter-influence of those cities will be enlarged. Since the highway between Shanghai (上海) and Nanjing (南京), which links Suzhou (蘇州), Wuxi (無錫), Changzhou (常州) and Zhenjiang (鎮江), is constructed and operated, it will influence the attractiveness of various cities. An estimator of the coefficient of highway to usual road is 0.6.[24] We assume that it will force the railway system to improve its efficiency respectively (for example, as 0.7), from present coefficient (of train to bus) 0.6 to a new coefficient 0.4 ($=0.6\times0.7$) in a period. Then, the inter-influence of those cities along this line will be enlarged, and, their estimators in the year 2005, under the same assumption as case 2, are listed in table 3.5, while the figures in brackets are those in an original condition.

Comparing above cases, we can see that different regional policies will result in different changes of interrelations among the city group in Yangtze River Delta. Now, let's go to the conclusions of the study.

4. Conclusions

In this paper, based on the empirical study of analysing the interrelations among the city group in Yangtze River Delta, we have proposed an economic

Table 3.4 The Variations of GDPs and City's Influences (Case 2)

City	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Nanjing (南京)	Zhenjiang (鎮江)	Yangzhou (揚州)	Nantong (南通)	Hangzhou (杭州)	Jiaxing (嘉興)	Huzhou (湖州)	Shaoxing (紹興)	Ningbo (寧波)	Zhoushan (舟山)
Sumed GDP (mil. *yuan*)	647230	246409	209912	109308	162451	87760	169792	134196	210142	96861	72711	119978	170882	33175
GDP per capita (*yuan*)	49735	43010	48909	32761	31138	33335	18086	17112	35143	29676	28781	28250	32475	33755
City influence	90.04	6.18	6.19	2.81	6.17	2.24	2.85	2.46	6.94	2.18	1.72	2.40	4.36	0.99
Influ. without impact	95.81	6.33	6.28	2.65	6.13	2.04	2.84	2.39	7.04	2.02	1.51	2.30	4.35	0.61
Increased rate	-6%	-2%	-1%	6%	1%	10%	0%	3%	-1%	8%	14%	4%	0%	61%

Note: Increased rate = (City influence − Influ. without impact)/Influ. without impact

Table 3.5 The Variations of Cities' Inter-influece when Traffic Condition is Improved (Case 3)

To＼City	Shanghai (上海)	Suzhou (蘇州)	Wuxi (無錫)	Changzhou (常州)	Zhenjiang (鎮江)	Nanjing (南京)
Shanghai	——	0.184 (0.126)	0.123 (0.083)	0.043 (0.027)	0.024 (0.014)	0.051 (0.034)
Suzhou	2.680 (1.901)	——	0.368 (0.249)	0.087 (0.055)	0.036 (0.022)	0.070 (0.047)
Wuxi	1.787 (1.267)	0.368 (0.251)	——	0.180 (0.113)	0.050 (0.030)	0.087 (0.058)
Changzhou	1.364 (0.968)	0.191 (0.130)	0.397 (0.268)	——	0.077 (0.047)	0.112 (0.074)
Zhenjiang	0.946 (0.671)	0.100 (0.069)	0.138 (0.093)	0.096 (0.061)	——	0.237 (0.157)
Nanjing	0.743 (0.527)	0.071 (0.048)	0.087 (0.059)	0.051 (0.032)	0.086 (0.052)	——

Note: The figures in brackets are the attractiveness of those cities in original condition.

24) According to the investigation from *Shanghai Bus Center*, both the *ratio of time* and the *ratio of fare* for highway can be calculated averagely based on observations. Then, by formula (2.8), both coefficients can be calculated.

influence model for cities. A city, city j, usually impose a certain economic influence on any city z, INF_{jz}, with travel distance d_{jz}, as:

$$INF_{jz}=\frac{f(P_j, var^1_j, \ldots, var^n_j)}{\{(GDP\text{-}av/GDP_j)^{\alpha}\times D_{jz}^{\gamma}\}} \qquad (4.1)$$

where f is a positively relative function; P_j is the population of city j; var^k_j are some indices of city's development of city j; GDP-av is the average GDP per capita involving all cities; GDP_j is the GDP per capita in city j; D_{jz} is the *converted distance* of real distance d_{jz}; α and γ are parameters.

The features of this model can be summarized as follows.

(1) The model is an improvement for Reilly model, by considering various kind of attractive factors of each city, such as an importance of a city, development level of a city, and traffic condition linking the city and another place. Because of this improvement, Casey model can be improved to be applicable to city group and a wide region.

(2) The model can give us a logical explanation for the divergence or convergence of regional economic development. The model can be calibrated under enough statistical data and, the policy variables affecting the regional development might be considered.

As an empirical study for the city group of Yangtze River Delta, some viewpoints for the development of this region can be concluded as follows:

(3) Were there no special regional economic policies, the regional development will be divergent, the economic gaps between Shanghai and its surrounding sub-regions will become larger and larger. Then, the whole region will become a uni-polar economy of Shanghai.

(4) If the regional policy of even development is adopted, many production processes can be transferred to other cities instead of remaining them in Shanghai. In this case, the disparity of city's influence will tend to be reduced.

(5) If the policy of even development is adopted, besides, the traffic conditions in the Yangtze River Delta are improved, then, the inter-influence of these cities will be enlarged. In addition to conclusion (4), the difference of city's influence will be reduced further rapidly.

Because of above consideration, the regional policy to develop Yangtze River Delta should consider short-term and long-term effects at the same time. As short-term effect, it should enhance the attractiveness of Shanghai through the exploiting of Pudong area. After a certain level of development in Shanghai is attained, it is required to utilize this attractiveness to develop the economies of surrounding cities instead of developing the suburban areas of Shanghai itself. This policy can be realized by transferring some industries such as labor-intensive and low-technology ones to the surrounding cities. For this purpose, one of the effective means is to construct high speed traffic system between Shanghai and these surrounding cities, since the improvement of traffic condition can largely strengthen the relationship between cities.

Further topics of the study will involve following ones. First, the capacity of transportation should be considered to improve the ***economic influence model for cities*** to be a concrete functional form; second, some links between the economic influence in the model and common economic indices (e.g. GDP etc.) should be considered more clearly.

Appendix

In order to consider the average shopping distance in residential areas, we assume that in a city, the population density in urban area and that in rural area are uniform respectively.[25] Although Casey's idea that there is one center in a town or township is reasonable in rural areas, the main problem is that we should find an index to determine how many shopping centers are there in a city including urban areas.

25) Since Shanghai is a super-large city in our study, we especially assume that in Shanghai, the population density in each *district* and that in each *county* are uniform respectively.

Considering hospitals,[26] they are usually located neighboring to a shopping center. Moreover, the location of a hospital is usually determined by the factor of residential density around it, which is very similar to the character in forming a shopping center. By studying the rural area of Shanghai, we have got 1) the ratios of the number of hospitals to the number of townships are rather stable;[27] 2) if we use the number of hospitals as an index to determine the number of shopping centers, it is rather concordant for the both variables of the average area dominated by each township and that dominated by estimated shopping center, since the correlation coefficient is 0.960.

So, the above index for the number of shopping center is rather concordant to the original idea in Casey model for the case of rural area. Also, this index provides us a possibility to estimate the number of shopping centers in urban areas. Therefore, the number of shopping center in each district or county of Shanghai can be estimated. And then, the shopping distance of residents can be calculated, which are listed in table A.1.

Based on above estimation, we can calculate the total average shopping travel distance of the entire city. The formula is as following:

$$\text{TOTAL AVERAGE SHOPPING TRAVEL DISTANCE} = \Sigma_i d_i (P_i / P_T)$$

where d_i is the average shopping distance in district/county i;
P_i is the population in district/county i:
P_T is the total population of the entire city, that is $P_T = \Sigma_i P_i$.

In this way, the total average shopping travel distance in Shanghai is 0.80.

The average shopping travel distance in other cities can be calculated similarly. The results of other 13 cities are listed in table A.2.

Table A.1 An Estimator of Shopping Distance for Each Country of District in Shanghai

County/District (1)	Land Area (sq. km.) (2)	Number of Estimated Center (3)	Dominating Area (sq. km.) (4)=(2)/(3)	Dominating Radius (km.) (5)=$\sqrt{[(4)/\pi]}$	Average Shopping Distnace (km.) (6)=(5)/2
Huangpu (黄浦区)	4.54	12	0.378	0.347	0.174
Jin'an (静安区)	7.62	14	0.544	0.416	0.208
Nanshi (南市区)	7.87	17	0.463	0.384	0.192
Luwan (盧湾区)	8.05	15	0.537	0.413	0.207
Hongkou (虹口区)	23.48	24	0.978	0.558	0.279
Zhabei (閘北区)	28.50	20	1.425	0.673	0.337
Changining (長寧区)	38.30	19	2.016	0.801	0.401
Yanpu (楊浦区)	52.13	20	2.607	0.911	0.455
Xuhui (徐匯区)	54.76	28	1.956	0.789	0.395
Putuo (普陀区)	54.83	18	3.046	0.985	0.492
Minhang (閔行区)	370.8	24	15.45	2.217	1.109
Baoshan (宝山区)	424.6	30	14.15	2.123	1.061
Jiading (嘉定区)	458.8	22	20.85	2.576	1.288
Pudong (浦東新区)	522.8	47	11.12	1.882	0.941
Jinshan (金山県)	586.1	21	27.91	2.980	1.490
Songjiang (松江県)	605.6	27	22.43	2.672	1.336
Qingpu (青浦県)	675.5	27	25.02	2.822	1.411
Fengxian (奉賢県)	687.4	27	25.46	2.847	1.423
Nanhui (南匯県)	687.7	34	20.23	2.537	1.269
Chongming (崇明県)	1041.2	39	26.70	2.915	1.458

26) The hospital in China is usually an idea of a medical institution with certain scale, in which some hospital beds are attached. The idea of hospital does not includes clinics.

27) Seven of the ten are between 1.23 an 1.36, the other three ones are 1.15, 1.16 and 1.56. That the ratio is larger than 1 can be explained that the rural area is so wide that some additional centers, besides towns, arise in some important areas.

Table A.2 The Estimator of Shopping Distance for Other 13 Cities

Cities		Land Area (sq. km)		Estimated Center		Dominating Area (sq. km)		Shopping Distance (km)		Population (×100)		Total Shopping
		urban	rural	urban	rural	urban	rural	urban	rural	urban	rural	Distance (km.)
Suzhou	(蘇州)	178	8310	133	180	1.34	46.2	0.33	1.92	1057	4672	1.62
Wuxi	(無錫)	397	4253	124	106	3.20	40.1	0.50	1.79	1075	3217	1.47
Changzhou	(常州)	187	4188	100	80	1.87	52.4	0.39	2.04	807	2530	1.64
Nanjing	(南京)	947	5569	237	79	4.00	70.5	0.56	2.37	2658	2559	1.45
Zhenjiang	(鎮江)	215	3628	85	69	2.53	52.6	0.45	2.05	525	2108	1.73
Yangzhou	(揚州)	148	12283	57	251	2.60	48.9	0.45	1.97	483	8905	1.90
Nantong	(南通)	121	7880	64	210	1.89	37.5	0.39	1.73	609	7233	1.62
Hangzhou	(杭州)	430	16166	72	342	5.97	47.3	0.69	1.94	1435	4544	1.64
Jiaxing	(嘉興)	973	2942	48	133	20.27	22.1	1.27	1.33	767	2497	1.31
Huzhou	(湖州)	1521	4296	52	105	29.25	40.9	1.53	1.80	105	2421	1.79
Shaoxing	(紹興)	101	7800	17	279	5.94	28.0	0.69	1.49	306	3941	1.43
Ningbo	(寧波)	1033	8332	73	272	14.15	30.6	1.06	1.56	1142	4120	1.45
Zhoushan	(舟山)	988	383	66	36	14.97	10.6	1.09	0.92	678	305	1.04

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