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Technology Finance and Urban Development: A Quantitative Approach to Shaping a New Future for Shrinking Cities

Qingle Chen

Shandong University of Finance and Economics (Shengjing Campus), Jinan, Shandong, 250220, China

Abstract. Using a dataset of 30 cities of different administrative levels in Liaoning Province, China, for the period 2007-2020, this study proposes a novel quantitative methodology for assessing the impact of socio-economic factors on the attractiveness of shrinking cities. By combining a shrinkage model with principal component analysis and extreme value normalisation of key indicators such as population size, GDP, retail sales of consumer goods, public budget expenditure, and secondary and tertiary employment, we provide a detailed analysis of the phenomenon of shrinking cities and its drivers. Using an interdisciplinary approach involving economics, psychology and sociology, we redefine traditional indicators for assessing the attractiveness of cities by analogising urban population dynamics to the process of molecular transfer in physical chemistry. This approach allows us to quantify the attractiveness of cities in four ways: socio-economic attractiveness, cost of living, public services and employment opportunities. The case study of Fushun illustrates the application of our model, revealing the potential for negative attractiveness across all dimensions and highlighting the multifaceted challenges facing shrinking cities. Our findings highlight the critical role of balanced socio-economic development, well-developed public services, affordable living conditions and adequate employment opportunities in enhancing the attractiveness of cities. This comprehensive framework provides valuable insights for urban planners and policymakers aiming to mitigate urban shrinkage and promote sustainable urban development.

Keywords: Urban Shrinkage; Socio-economic Factors; Quantitative Evaluation; Principal Component Analysis; Sustainable Urban Development.

1. Introduction

In recent years, the phenomenon of urban shrinkage has attracted much attention from urban planners and researchers. This paper attempts to explore the complexity of urban shrinkage in Liaoning Province, China, by examining a range of socio-economic indicators for thirty cities of different administrative levels. Through the use of shrinkage modelling and principal component analysis, this study aims to quantify urban shrinkage and its drivers from 2007 to 2020, and to provide a refined classification of the cities in question. By applying a polar normalisation approach, we have standardised the data on population size, GDP, retail sales of consumer goods, public budget expenditures, and employment in the secondary and tertiary sectors, allowing for a nuanced analysis of socio-economic factors [1]. The rationale for this approach stems from the complexity of the causes of urban shrinkage, which depend largely on the spatial and temporal dynamics of demographic change. Recognising the multifaceted impact of socio-economic factors on urban demographic trends is crucial to understanding the trajectory of shrinking cities. In this paper, we innovatively draw parallels between urban population dynamics and the molecular transfer processes observed in physical chemistry, conceptualising cities as solvents and populations as solutes [2]. By adopting the concept of chemical potential, we give new meanings to traditional terms, thereby constructing a novel approach to assessing the attractiveness of cities in terms of four dimensions: socio-economic attractiveness, cost of living, public services and employment opportunities [3]. This interdisciplinary analysis not only highlights the importance of selecting appropriate indicators to quantify the attractiveness of cities, but also paves the way for a comprehensive assessment of the socio-economic impact on shrinking cities.

2. Related Work

To address the key issue of urban population shrinkage, this study comprehensively explores the socio-economic determinants affecting the population dynamics of thirty prefecture-level cities in Liaoning Province. By combining a shrinkage model with principal component analysis and standardising the data using extreme value normalisation, we provide an in-depth study of the extent of urban shrinkage and its intrinsic drivers over the period from 2007 to 2020 [4]. This approach not only helps to refine the classification of cities according to their shrinkage status, but also provides insights into the interactions between demographic change and socio-economic factors.

The study draws an analogy between the process of urban population mobility and the process of molecular transfer in physical chemistry, innovatively conceptualising cities as solvents and populations as solutes. This analogy enables the application of chemical potential theory to redefine traditional indicators of urban attractiveness through a multidisciplinary lens of economics, psychology and sociology [5]. By examining socio-economic attractiveness, cost of living, public services and employment opportunities as key dimensions of urban attractiveness, we quantitatively assess the impact of these factors on population retention and attraction.

The analytical framework argues that a city's attractiveness is directly proportional to its ability to meet the future development aspirations of its residents, and that indicators that accurately reflect a city's attractiveness must therefore be carefully selected. Through a detailed assessment of socio-economic factors, living standards, public services and employment opportunities, the study reveals a comprehensive impact assessment that suggests that the combined impact of these dimensions largely determines urban demographic trends.

The case of Fushun City selected for this study highlights the practical application of our model, showing negative potential for urban attractiveness on all measured dimensions, indicating a lack of sufficient pull factors to retain or attract population. Despite Fushun's significant efforts to improve employment opportunities, its low GDP and other deficiencies highlight the complex challenges facing shrinking cities. The methodology of this study provides an important tool for urban planners and policy makers by quantitatively assessing the socio-economic factors that influence the attractiveness of a city. It underscores the need for a holistic approach that strengthens socio-economic development, public services, living standards and employment opportunities to effectively mitigate urban shrinkage.

3. Modelling

There are various common definitions of shrinking cities. In this paper, we study 30 cities at sub-provincial, municipal, county and city levels in Liaoning Province, mainly considering quantitative indicators such as population size, GDP, total retail sales of consumer goods, general public budget expenditure, number of employed persons in urban units_secondary and tertiary industries, etc., and applying the contraction model and principal component analysis to measure and analyse the contraction degree of the cities and the driving force from 2007 to 2020 to judge the contraction of the cities, and to make a fine classification [6].

This paper mainly adopts the extreme value normalisation method for data normalisation. Extreme value normalisation is to further analyse the attributes of the data by scaling the attribute data so that it falls into a small specific interval, such as [-1,+1], [0,1], and so on. In this paper, the data of each economic and social element is normalised to the interval [0,1]. Separately, the raw data of the individual economic and social elements are normalised, and the polar normalisation formula:

$$\tilde{X}_t = \frac{X_t - X_{min}}{X_{max} - X_{min}} \tag{1}$$

Where X_{min} denotes the minimum value of each indicator, X_{max} denotes the maximum value of each indicator, and X_k denotes the quantitative indicator in year t.

The causes of the phenomenon of urban contraction are complex, and whether the city is contracting is mainly based on the changes in the number of population in a certain amount of time and space as a judgement [7]. In reality, it is necessary to consider the economic and social factors have different degrees of influence on the change of population in shrinking cities, so as to understand the impact of economic and social factors on urban development. Therefore, it is important to investigate the relationship between population size and economic and social factors.

In the process of researching the attractiveness of cities to population, we found that the process of population transfer is very similar to the process of molecular transfer, there is an individual independent irregular movement, but at the same time there is a systematic overall regular change. Therefore, the population flow between cities is analogous to the process of molecular transfer of physical and chemical heat equilibrium, the city is compared to a solvent, the population is compared to a solute; the process of population increase in the city can be regarded as a dissolution, and the process of urban population outflow can be regarded as the precipitation of the solute. With reference to the definition of chemical potential, we combine the similarities between the two fields and give new meanings to each part of the definition as shown in Table 1.

Table 1. Conversion of the chemical meaning of the symbols into the meaning in this paper

Symbolic	Chemical meaning	Implications of this article
Δn	Number of activated molecules	Changes in the number of urban populations
α	-	Adjustable externalities
αE	Activation energy	Quantitative influences
$m(t)$	Increase in activation molecules	Population inflow
$n(t)$	Decrease in activated molecules	Population outflow
λ	Retroactivity	Repetition rate
Φ	Chemical potential	City attraction potential

The value of αE should be between 0,1, and the closer to 1, the stronger the attractiveness of the city, and vice versa, the poorer the attractiveness. According to the model assumption $m(t) = n(t)$, the formula for the change in the number of urban population Δn is.

$$\Delta n = \alpha E\{m(t)[1 - \lambda e^{-\Phi}] - n(t)e^{-\Phi}\} \tag{2}$$

Unlike chemical potential, the elements influencing demographic attractiveness are multidisciplinary, including economics, psychology and behaviour. Whether a city is attractive to people depends on whether the various environmental factors that the corresponding city can provide for people will touch the threshold of people's expectations for future development [8]. Therefore, the selection of indicators plays a fundamental role in quantitatively evaluating the level of population attractiveness. The model considers four dimensions, namely socio-economic, cost of living, public services and employment, and seeks the attractiveness potential of each of these four dimensions, as discussed in detail below.

The attraction potential of the city is categorised below. The socio-economic attractiveness of a city is based on its GDP, and the attractiveness of its living costs is based on its total retail sales of consumer goods and investment in property development (housing). The public services attraction potential considers general public budget expenditure, domestic water supply and hospital beds [9]. Employment attractiveness mainly takes into account the number of employed persons in urban units (secondary and tertiary industries), investment in fixed assets (excluding farm households) and total industrial output value above designated size.

4. Analysis of Influencing Factors

Let us assume a situation that a city is neither attractive nor repulsive to the population, i.e., Δn = 0. From the above formula for the change in the number of people in a city, we can find out that in this case, $\phi_* = 0.434log_{10}(\frac{n+\lambda}{m})$, and it is clear that when $\phi > \phi_*$, the city is attractive to the population, and when $\phi < \phi_*$, the city is repulsive to the population. The $m(t), n(t)$ in the model is a function of time, and when these values are difficult to obtain, we can take their average values

For αE, we will go through the optimistic and pessimistic estimates of the impact of the influence factors on the attraction of the urban population in the well-categorised categories in order to arrive at more reliable impact coefficients for each indicator [10].

Since $\phi > 0$, we first consider the optimistic case of αE: when the influencing factor is very attractive to the population, it is conceivable that the number of population losses $n(t)$ and the rate of population return λ will be reduced so much that they can be ignored. This leads to:

$$\alpha E_A = \frac{\Delta n_1}{m_1} \tag{3}$$

Next, we consider the more pessimistic scenario: that is, when the policy is not sufficiently attractive or even repulsive to the population, the attraction potential ϕ will be much reduced, and combined with the assumption that $\alpha E > 0$, it can be shown that $e^{-\Phi}$ is close to 0. This follows:

$$\alpha E_B = \frac{\Delta n_2}{m_2} \tag{4}$$

Combined with the above, we can derive the following optimised estimates of the policy factors:

$$\alpha E_{average} = \frac{\alpha E_A + \alpha E_B}{2} = \frac{\Delta n}{2m} \tag{5}$$

Socio-economic attraction, Generally speaking, cities with higher GDP are seen as more prosperous in terms of development and are attractive to people. With only the GDP influence, there are:

$$E_1 = c_1 C \tag{6}$$

Socio-economic attraction potential for:

$$\Phi_1 = 0.434log_{10}\frac{\frac{\lambda m + n}{\Delta n}}{m + \frac{\Delta n}{\alpha E_1}} \tag{7}$$

Where: c is the standardised GDP indicator quantity and c_1 is its weighting factor.

The price of life attracts, in today's era, people's need for a better life is growing, food and accommodation is still the basis of people's life, therefore, the city's consumption standards and housing conditions become still an important basis for people to choose the city. Taking food and accommodation as the criteria for choosing a city, there are:

$$E_2 = d_1 D_1 + d_2 D_2 \tag{8}$$

The living sex-price attraction potential is:

$$\Phi_2 = 0.434log_{10}\frac{\frac{\lambda m + n}{\Delta n}}{m + \frac{\Delta n}{\alpha E_2}} \tag{9}$$

Where: D_1, D_2 denote the standardised indicator quantities of total retail sales of consumer goods and investment in real estate development (residential) respectively, and d_1, d_2 are their weighting coefficients respectively.

Public service attraction, urban infrastructure and public services is a major indicator of urban development, is necessary to achieve the integration of economic, environmental and social benefits, is the fundamental guarantee of the residents' life, infrastructure is complete for the attractiveness of the city is particularly important [11]. Considering general public budget expenditure, domestic water supply and hospital beds, there are:

$$E_3 = f_1F_1 + f_2F_2 + f_1F_1 \tag{10}$$

The public service attraction potential is:

$$\Phi_3 = 0.434log_{10}\frac{\frac{\lambda m + n}{\Delta n}}{m + \frac{\Delta n}{\alpha E_3}} \tag{11}$$

Where: F_1, F_2, F_3 denote the standardised indicator quantities of general public budget expenditure, domestic water supply and hospital beds respectively, and f_1, f_2, f_3 are their weighting coefficients.

Employment job attraction, The main purpose of most people choosing cities is to be able to get better job opportunities and have optimistic career prospects, so the career development of the city is an important basis for the population to decide the city. Measuring the attractiveness of a city by the number of employed persons in urban units (secondary and tertiary industries), investment in fixed assets (excluding farm households) and total industrial output value above the scale, there are:

$$E_4 = h_1H_1 + h_2H_2 + h_1H_1 \tag{12}$$

Employment work attracts potential for:

$$\Phi_4 = 0.434log_{10}\frac{\frac{\lambda m + n}{\Delta n}}{m + \frac{\Delta n}{\alpha E_4}} \tag{13}$$

Where: H_1 , H_2 , FH_3 denote the standardised indicator quantities of general public budget expenditure, domestic water supply and hospital beds respectively, and h_1 , h_2 , h_3 are their weighting coefficients.

In summary, the larger the value of $E_i(i = 1,2,3,4)$, the greater the influence of this factor on the urban population change and summing up all the factors, there are:

$$\alpha E = \sum_{k=1}^{4} E_k \tag{14}$$

Get the comprehensive impact of economic and social elements on urban population change. Where α is adjustable external factor, adjust the final obtained αE to 1, that is:

$$\alpha = \frac{1}{E_1 + E_2 + E_3 + E_4} \tag{15}$$

5. Model Solving

Taking Fushun City, a shrinking city, as an example, according to the population attraction model given above, combined with the known data of economic and social factors, the impact of different degrees of population in shrinking cities is quantitatively analysed.

Firstly, the influence factors of positive society and elements on population change are obtained through principal component analysis. It is shown in Table 2 below.

Table 2. Influence factors of elements on population change obtained by principal component analysis

Economic and Social Factors	Impact Factor
GDP_Municipal districts	0.1546
Total Retail Sales of Consumer Goods_City District	0.1379
Fixed Asset Investment (Excluding Farming Households)_City District	0.1002
General Public Budget Expenditure_Municipal	0.1712
Industrial Output Value Above Scale_Municipal District	0.1111
Number of Employed Persons in Urban Units_Second and Third Industries_Municipal District	0.1458
Water Supply for Domestic Use_Municipal	0.0908
Investment in Property Development_Municipal	0.0886

Next, the scores for the socio-economic factor, the cost of living factor, the public service factor and the employment and work factor were calculated using the formula above:

$$E_1 = 1.069 \quad (16)$$

$$E_2 = 1.201 \quad (17)$$

$$E_3 = 1.663 \quad (18)$$

$$E_4 = 1.952 \quad (19)$$

Adjustable external factor $\alpha = 0.1699$. regression curve for the number of household population over time, Δn can be approximated by 10,000 times the slope, with a correlation coefficient of 0.9609. calculated according to the previous formula for the city's attraction potential:

$$\Phi_1 = -0.3346 \quad (20)$$

$$\Phi_2 = -0.3165 \quad (21)$$

$$\Phi_3 = -0.2683 \quad (22)$$

$$\Phi_4 = -0.2458 \quad (23)$$

According to the definition of the city attraction potential can be seen, only when $\Phi > 0$, the city is attractive to the population, obviously, Fushun city socio-economic factors, living price factors, public service factors and employment and work factors are not attractive to the population, and the population is losing in a certain degree.

Among them, we can see that Fushun's employment work attraction potential is the largest, it can be inferred that the population stays in the city, mainly because of the influence of the aspect; while the economic attraction potential is low, combined with the actual Fushun city's GDP is low, it is difficult to keep people. Breakdown of economic and social factors on the impact of population change in Fushun, according to the relevant elements of the impact factor can be seen: in the second and third industry urban unit employment in the employment work factor occupies a major position; social consumption also plays an important role in the price of living factors; and the general public budget expenditures of the largest impact on population change.

6. Conclusion

This study presents a comprehensive methodology for quantitatively assessing the impact of socio-economic factors on the attractiveness of shrinking cities, using Fushun City as an example. Our analytical framework incorporates the shrinkage model and principal component analysis for a range of quantifiable indicators such as population size, GDP, retail sales of consumer goods, public budget expenditures, and secondary and tertiary employment for 30 cities in Liaoning Province from 2007 to 2020. By normalising the data using the extreme value normalisation method, we establish a structured approach to carefully assess urban shrinkage and its drivers.

At the heart of our assessment lies an analogy between urban population dynamics and the process of molecular transfer in physical chemistry, where the city is seen as the solvent and the population as the solute. This analogy allows us to define the attractiveness potential of cities using concepts such as chemical potential, incorporating factors such as the economy, lifestyle cost-effectiveness, public services and employment opportunities. We quantify each factor to determine its contribution to the overall attractiveness of the city in order to establish a correlation between socio-economic factors and demographic change.

Our results show that the combined effects of these factors are quantified through a novel application of chemical potential theory, which provides a nuanced understanding of urban attractiveness. Specifically, analyses of Fushun show that despite the city's efforts in various areas, its overall attractiveness remains negative, indicating a continued population decline. This decline highlights the need for targeted policy interventions to address the multifaceted nature of urban attractiveness, especially in cities facing the challenge of shrinkage.

The methodology presented in this study provides a robust framework for policymakers and urban planners to assess and improve factors of urban attractiveness. By quantifying the impact of socio-economic variables, this approach allows for a strategic focus on improving areas that are critical to reversing urban shrinkage, ultimately promoting sustainable urban development and growth.

7. Discussion

The phenomenon of urban population shrinkage is multifaceted, particularly as observed in the cities of Liaoning Province, and provides a compelling case for a comprehensive study of the socio-economic factors that influence urban population dynamics. Through the meticulous application of shrinkage modelling and principal component analysis, this study not only quantifies the phenomenon of urban population shrinkage, but also reveals the intrinsic drivers of urban population shrinkage from 2007 to 2020. Extreme value normalisation of data from different domains ranging from population figures to GDP, retail sales, public budget expenditures and employment statistics helps to provide insights into the relationship between urban development and socio-economic factors. Similar to molecular transfer in physical chemistry, this study conceptualises the city as a solvent and the population as a solute, and adopts a chemical potential framework to analyse population attraction and mobility in an urban environment.

The methodology employed delineates the attractiveness of cities in terms of four dimensions: socio-economic attractiveness, cost-of-living effectiveness, public services, and employment opportunities, which are critical to understanding how each factor, individually or collectively, affects urban demographic trends. The innovative approach of quantifying these dimensions through chemical potential theory allows for a nuanced assessment of urban attractiveness. The results of this analysis, and in particular the case study of Fushun City, reveal the nuances of urban attractiveness where, despite certain efforts, the overall magnetism of the city is not sufficient to halt or reverse the trend of population decline.

The quantitative assessment methodology developed in this study is an important tool for urban planners and policy makers to be able to centrally identify strengths and weaknesses within the socio-economic framework of shrinking cities. It emphasises the importance of a balanced approach that promotes socio-economic development, improves public services, provides cost-effective living, and creates substantial employment opportunities to enhance urban attractiveness. Ultimately, the study highlights the complexity of the phenomenon of urban shrinkage and the key role of socio-economic factors in influencing urban demographic trends, providing a basis for strategic interventions aimed at revitalising shrinking cities.

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