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Abstract: Three urban growth theories predict parallel growth of cities. The endogenous growth theory predicts deterministic parallel growth; the random growth theory implies that city growth follows Gibrat's law with a steady-state distribution; and the hybrid growth theory suggests the co-movement of random city growth. This paper uses the Chinese city size data from 1984-2006 and time series econometric techniques to test for parallel growth. The results from various types of stationarity tests on pooled heterogeneous cities show that city growth is random. However, once growth trend and structural change are taken into account, certain groups of cities with common group characteristics, such as similar natural resource endowment or policy regime, grow parallel.

Keywords: Urban growth, Parallel growth, Zipf's law, Unit root, Structural change

JEL Classification: C22, R11, R12

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1. Introduction

City growth across countries exhibits two striking facts. First, cities keep growing in many countries, in terms of both city size (city population) and the number of cities. Second, the distributions of city sizes in different countries fit the power law (Pareto distribution) very well. Especially, in the upper tail of city size distribution, the power exponent is equal to or very close to one, which is called Zipf's law or rank-size rule, meaning that a city size is proportional to the inverse of its rank.[1]

Correspondingly, three strands of theories have been developed to explain the two stylized facts. The endogenous urban growth theory (Black and Henderson, 1999; Eaton and Eckstein, 1997) uses human capital externalities as the driving force to explain the persistent and deterministic growth of cities, and concludes that in steady state, city sizes grow at a constant rate proportional to the growth rate of human capital accumulation, which is dubbed parallel growth. The random urban growth theory (Gabaix, 1999) assumes city growth as a random walk and shows that in steady state city size distribution obeys Zipf's law. The hybrid urban growth theory (Rossi-Hansberg and Wright, 2007) employs both human capital externalities and stochastic productivity shocks. Under some restrictive conditions, the hybrid model can generate both balanced endogenous growth and city size distribution close to Zipf's law. It is worth noting that another urban growth theory—locational fundamentals theory (Fujita and Mori, 1996; Krugman, 1996), is also relevant although it makes no clear prediction about the pattern of city growth. This theory emphasizes the persistent impact of initial location conditions on future city growth, which is to some degree related to the random growth theory.

A recent simulation study by Gan, Li, and Song (2006) demonstrates that the very good fit

[1] There is rich literature on city size distribution. Let *R* and *P* denote the rank and population size of a city, then, the power law or Pareto distribution implies that the number of cities whose population exceeds *P* is proportional to $P^{-\beta}$. The econometric specification is $\ln R = \alpha - \beta \ln P + \varepsilon$. With $\beta = 1$, it is called Zipf's law (Zipf, 1949) or rank-size rule. However, to be specific, rank-size rule is only a good approximation of Zipf's law (Gabaix, 1999). Many studies find that the upper tail of city size distribution obeys Zipf's law quite well. For a comprehensive survey on city size distribution, see Gabaix and Ioannides (2004).

of Pareto distribution is just a statistical phenomenon.[2] Therefore, the more interesting focus should be to study the dynamics of urban growth process and growth determinants. Unfortunately, empirically, we are still not clear whether city growth is random or deterministic. If it is deterministic, does the growth converge (small cities grow faster), diverge (large cities grow faster), or parallel (all cities grow at the same speed)?[3]

Of particular interest is to test the parallel growth hypothesis. Whether Zipf's law for all cities is a statistical property or not, the relative stability of city size distribution in a country at different time periods suggests that cities of different sizes may grow relatively parallel. As a matter of fact, all the three urban growth theories are somewhat related to parallel growth. The endogenous urban growth theory predicts simple, deterministic, parallel growth; the random growth theory assumes the same average growth rates with common variance (Gibrat's law) and predicts a steady-state size distribution; and the hybrid model predicts co-movement of random growth processes (cointegration in terms of time series econometrics). The goal of this paper is to test for the parallel growth of cities. Specifically, we use the Chinese city size time series data from 1984 to 2006 to identify the dynamic pattern of city growth. The results from various types of stationarity (unit roots) tests show that in general city growth is not parallel; however, once trend stationarity with endogenous structural change are allowed, cities with certain common group characteristics, in terms of geographic region, natural resource endowment, and policy regime, grow parallel. If any location-specific factors are considered location fundamentals, then our findings lend some support to the locational fundamentals growth theory in the sense that cities with similar location fundamentals tend to grow parallel.

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[2] Gan, Li, and Song (2006) show that the high R^2 of the regression of rank on size is just a statistical property. However, their estimated values of β are sensitive to the parameters of the distribution of the size variable. They argue that Zipf's law is just a statistical phenomenon, but, to be precise, their conclusion means that the Pareto distribution is a statistical phenomenon.

[3] Following economic growth theory (Barro and Sala-i-Martin, 2004), if small cities grow faster than large cities without conditional on any other characteristics of city economies, it is referred to as *absolute convergence*, meaning that all cities will converge to the same long-run steady state size. If different cities converge to their own steady state sizes, it is called *conditional convergence*. If small cities grow faster than large cities after holding fixed some other variables, such as initial human capital stock, government policies, it is called β *-convergence*. If the dispersion of city sizes (say, the standard deviation of sizes of a group of cities) declines over time, it is referred to as σ *-convergence*.

The rest of the paper is organized as follows: Sections 2, 3, and 4 review the three urban growth theories and their empirical evidence, and discuss the corresponding methodology of testing for parallel growth, respectively. Section 5 describes the data set; section 6 presents the results; and section 7 concludes.

2. The endogenous urban growth theory

The endogenous urban growth theory predicts deterministic, parallel growth of cities, meaning that in steady state cities of different sizes grow at the same constant speed. The Black-Henderson model (Black and Henderson, 1999) assumes localized information spillovers and human capital accumulation as the engines of urban growth. This model produces endogenous city sizes and number of cities over time. Sizes of different types of cities grow at the same rate which is proportional to the growth rate of human capital accumulation; the number of cities of each type also grows at the same rate which equals the difference between the rate of national population growth and the rate of city population growth. A similar, deterministic, endogenous growth model by Eaton and Eckstein (1997) also predicts that the growth of a system of cities is parallel, with relative city sizes depending upon the knowledge spillover effects that cities can provide.

A direct testing for the deterministic, parallel growth is straightforward: We can test whether individual cities' growth rates are constant and remain the same over a long period. An alternative would be to split the sample into a few groups by size and to test whether the growth rate of each group is the same. Obviously, since city growth is affected by many factors (Angel, Sheppard, and Civco, 2005), such a strict parallel growth pattern is very rare to find, if not impossible. An indirect way is to test whether the size distribution of cities over a long period is stable or not. But the issue is that even though the size distribution is stable over time, an individual city's ranking may change. Eaton and Eckstein (1997) use France and Japan city size data and estimate the Markov transition matrix of city size evolution. They conclude that a wide range of city size growth is persistent, with quite stable distribution which is close to the rank-size rule. This is

consistent with parallel growth. However, there are a few problems in their study. First, they use only the top 40 urban areas. As many studies have pointed out, the threshold of city size matters in estimating the power exponent. Second, as pointed out by Sharma (2003), they do not provide statistical inference concerning the estimated transition probabilities. It is hard to know how large the diagonal transition probability should be to justify the persistent, parallel growth. Third, they do not discuss the stationarity of the city size time series data. If sizes of individual cities are not stationary, then, the better way to test the co-movement of city growth would be to conduct cointegration test, which is one of the goals of this paper. Finally, the period of rapid industrialization and urbanization in each country is also accompanied by dramatic changes in economic structure and policy regime, which may have had persistent effects on later urban growth and different impacts on different cities. Therefore, structural changes should also be taken into account.

Other possibilities of deterministic urban growth would be convergence and divergence. During the process of urbanization, new small cities keep forming and catch up with large ones, so the size distribution of cities would become more even over time, or cities with different initial sizes may converge to a common steady-state size. In contrast, urbanization could take the form of the expansion of existing large cities, which implies that city size distribution would be more unequal or diverge over time. In the Black-Henderson model, under some special constraints, cities could achieve steady-state levels, meaning that cities will grow and converge to a common stationary size. However, in another paper by Black and Henderson (1997) transitions are modeled as a stationary first-order Markov process and the relative size distribution of cities is astonishingly stable over time, with the actual distribution fluctuating little between decades and exhibiting no tendency to converge, diverge, or go bimodal. It is worth noting that an early study by Rosen and Resnick (1980) shows that large cities grow faster than small cities in most of the countries in their sample.

3. The random urban growth theory

The random urban growth theory assumes that city sizes grow stochastically, to be specific,

follow Gibrat's law (the growth processes have the common expected city growth rate and a common standard deviation), or in the continuous case, follow a geometric Brownian motion. If at least for a certain range of size, the cities follow Gibrat's law, then, regardless of whatever drives city growth, automatically in the steady state, the distribution of city sizes in that range will follow Zipf's law with a power exponent of one (Cordoba, 2007; Gabaix, 1999). If this theory is correct, the future research should focus on finding if and on explaining why the actual city size growth follows Gibrat's law.

The Gibrat's law implies that the city size growth process is a random walk or unit root process. To see this, consider a city with population N_0 at starting time 0. The growth rate of population at time *t*, g_t, is a random variable independently distributed with mean $E(g_t) = \mu$ and variance $Var(g_t) = \delta^2$, then

$$N_T = N_0 \prod_{t=1}^{T} (1 + g_t).$$

If g_t is relatively small, then the following approximation holds:

$$\ln N_T = \ln N_0 + \sum_{t=1}^{T} g_t = \ln N_0 + \mu T + \sum_{t=1}^{T} \varepsilon_t, \qquad (1)$$

where "ln" denotes logarithm and ε_t is a white noise process. Equation (1) implies that $\ln N_T$ is a random walk with a drift parameter μ and that a random growth shock has a permanent impact on city size.

There are three strategies to test the random growth theory. First, does city size distribution follow Zipf's law? Second, do growth processes of cities follow Gibrat's law, or in general, follow a random walk? Third, does a temporary random shock have permanent effects on city size evolution? The negative answer to any of the three questions would cast doubt on the random growth hypothesis. Note that from the perspective of time series econometrics the second and third testing strategies boil down to unit roots or stationarity test.

Davis and Weinstein (2002) find that one of the most powerful shocks to city size evolution in the human history—the Allied bombing of Japanese cities during the World

War II—has only temporary effects: Most cities return to their relative positions in the distribution of city sizes within about fifteen years from the devastating destruction. This strongly strikes at the random growth theory. Brakman, Garretsen, and Schramm (2004) and Bosker et al. (2008) apply the similar methodology and also find that city growth in Eastern Germany follows a random walk but city growth in Western Germany does not, suggesting that different post-war economic systems may have played an important role in shaping urban growth dynamics.

4. The hybrid urban growth model

The hybrid urban growth model proposed by Rossi-Hansberg and Wright (2007) combines both the endogenous growth model and Gibrat's law and is able to predict both city growth facts. A random total factor productivity shock is introduced to the model so that the balanced growth of city sizes is also random. Under two sets of restrictive conditions (eliminating physical capital or AK type model without human capital), the expected long-run growth rate and variance are independent of city size, which fits Gibrat's law. Under certain range of parameter values, the hybrid model can also generate distributions which deviate from Zipf's law, as uncovered by some empirical literature.[4]

The hybrid urban growth theory has been tested by Sharma (2003). Sharma uses the Indian decennial population census data from 1901-1991 and conducts unit roots and cointegration tests. She concludes that city growth may be parallel in the long run, but the short-run growth may deviate from the long-term rate of growth due to exogenous shocks; and temporary shocks may take less than a decade to dissipate.[5] However, Sharma specifies a very strong assumption that the time trend of growth is zero or very small and negligible, in order to produce parallel growth.[6]

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[4] *AK* model is the simplest endogenous growth model in economic growth theory. *AK* refers to a production function using only capital *K* and dependent on an exogenous technology shift denoted by *A*.

[5] It is interesting to note that Sharma's empirical study is done before Rossi-Hansberg and Wright's theoretical work. A careful reader can find that Sharma's paper provides empirical evidence for Rossi-Hansberg and Wright's conclusion that cities grow parallel in steady state yet the growth processes follow Gibrat's law.

[6] Sharma (2003) specifies the following model to test parallel growth: $\ln P_{it} = \alpha_i + \delta t + \beta_i \ln P_{j,t-1} + \varepsilon_{it}$.

To see this, let P_{it} denote the population of city *i* at time *t*, and assume that $\ln P_{it}$ is a general first-order autoregressive (*AR*(1)) process with a unit root, a drift, and a time trend:

$$\ln P_{it} = \alpha_i + \beta_i t + \ln P_{i,t-1} + \varepsilon_{it}.$$

The expected growth rate $E(g_{it})$ at time *t* is

$$E(g_{it}) = E(\ln P_{it} - \ln P_{i,t-1}) = \alpha_i + \beta_i t.$$

By the same token, the expected growth rate of city *j* at time *t* is

$$E(g_{jt}) = E(\ln P_{jt} - \ln P_{j,t-1}) = \alpha_j + \beta_j t.$$

The random parallel growth requires that for any *t*,

$$\alpha_i + \beta_i t = \alpha_j + \beta_j t.$$

Therefore, parallel growth implies the same time trend across all cities, regardless of the magnitude of time trend. The long-run equilibrium relationship between two city sizes with parallel growth is

$$\ln P_{it} = \alpha_i + \ln P_{jt}.$$

Since both $\ln P_{it}$ and $\ln P_{jt}$ are likely to be unit root processes, the cointegration relationship should be tested before making any estimation. The regression model for cointegration test is specified as

$$\ln P_{it} = \alpha_i + \gamma \ln P_{jt} + \varepsilon_{it}, \qquad (2)$$

where P_{jt} is the population level of a chosen reference city. If $\ln P_{it}$ and $\ln P_{jt}$ are cointegrated and $\gamma \neq 1$, then city *i* grows at a rate different from the reference city *j* . If $\ln P_{it}$ and $\ln P_{jt}$ are cointegrated and $\gamma = 1$, then the two cities grow parallel at the same expected long-run rate. Based on equation (2), we will test parallel growth for a few groups of cities in section 6.3.

Another relevant but hard-to-test theory—locational fundamentals theory (Fujita and Mori, 1996; Krugman, 1996), is also worth discussion here. Locational characteristics may be

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She argues that $\beta_i = 1$ implies parallel growth. This is true only if the time trend δ is zero or δ is very small and can be neglected.

considered randomly distributed over space (a spatial random process). They are the initial conditions which play a crucial role in shaping the formation and evolution of the size of that location. Even the initial conditions become unimportant any more, their effects may still persist, which is called the path dependence effect or the lock-in effect of self-reinforcing agglomeration forces (Fujita and Mori, 1996). Strong location-specific advantages may even revert the strong temporary shocks to city growth. However, this theory makes no clear prediction of the pattern of urban growth. Davis and Weinstein (2003) use the soon recovery of Japanese cities and Brakman, Garretsen, and Schramm (2004) the recovery of Western Germany, after the World War II bombing, as the confirmation of locational fundamentals theory.

5. Data

Before introducing the data, let's first summarize our testing methodology based on the three urban growth theories. We will test whether Chinese city sizes obey Zipf's law; if not, we will reject the random urban growth theory. We will also test whether Chinese city sizes follow Gibrat's law or unit root processes; if yes, we will proceed to test for parallel growth. For parallel growth test, we use a modified cointegration test strategy which will be explained in detail in section 6.3.

Our various tests use the Chinese city size data from 1984 to 2006. The data are from each year's *China Urban Statistic Yearbook.* In this paper a city is defined as "city proper," including both inner city area and suburban areas but excluding independent suburban counties.[7] City population is defined as the number of non-agricultural population in urban area of a city (by the permanent residence) at year-end. Non-agricultural population are those who engaged in non-agricultural vocations and their dependents.

Chinese cities usually are classified into five size categories according to their population:

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[7] Although some independent suburban counties, officially speaking, belong to the administrative scope of a city, they do not actually function like an urban area. Therefore, the *China Urban Statistical Yearbook* advises users to use "city proper" when studying urban related issues.

small, medium, large, extra large, and super large-sized cities with population less than 200,000, between 200,000 and 500,000, between 500,000 and 1,000,000, between 1000,000 and 2,000,000, and above 2,000,000 persons, respectively. By region, Chinese cities traditionally are assigned to one of the following three categories: Eastern, Middle, and Western region. A more disaggregated regional classification includes seven sub-regions: Northeastern, Northwestern, Southwestern, Northern, Eastern, Southern, and Middle China.

During the transition to a market-oriented economy and opening to the world, Chinese government has favored a small number of cities to implement reform and open policies. These include 5 cities in special economic zones and 16 open coastal cities (starting from 1980).

Rapid urbanization has taken place in China since the 1980s. The urbanization rate increases from 23.01% in 1984 to 43.90% by the end of 2006. Almost every year, there are new cities coming into being, and the total number of cities increases from 295 in 1984 to 661 in 2006.

The dramatic change of Chinese economic structure and policies may have had strong impacts on the evolution of city sizes and size distribution. Some cities benefit from the strong agglomeration economies from nearby super-large cities or city-belt; some other cities, however, still suffer from locational disadvantages. Cities in special economic zones have been blessed by favorable government economic policies and grow much faster. In addition, cities in the same region but of different sizes may have different growth patterns. These special features of Chinese city growth have attracted a few studies (Anderson and Ge, 2005; Song and Zhang, 2002). However, no studies have been done on the dynamics of Chinese city growth.

Our research focuses on identifying the growth pattern of Chinese cities. Do Chinese cities grow randomly, deterministically parallel, or with a constant long-run rate but short-run deviation? The analysis and answers are presented in the next section.

6. Results

6.1 Time Variations of Zipf's Exponent

The random urban growth theory states that if city growth processes follow Gibrat's law, then the steady state distribution will obey Zipf's law. Therefore, if the Chinese city size distribution is not consistent with Zipf's law, we would cast doubt on the random growth. We estimate the standard rank-size model for each year to trace the change of the power exponent and the stability of city size distribution:

$$\ln R = \alpha - \beta \ln P + \varepsilon, \qquad (3)$$

where R and P are the rank and population size of a city, and β is Zipf's exponent. Table 1 reports the estimated coefficient β.

Table 1

Time variations of the Zipf's exponent

	All cities		Cities with population >200,000		Cities with population >500,000		Balanced panel
Year	Number of cities	β	Number of cities	β	Number of cities	β	β
1984	295	0.891	131	1.266	50	1.463	0.879
1985	324	0.856	146	1.275	52	1.459	0.895
1986	342	0.857	149	1.260	54	1.447	0.904
1987	382	0.884	158	1.260	55	1.445	0.904
1988	434	0.927	168	1.273	58	1.440	0.919
1989	450	0.932	175	1.282	58	1.429	0.925
1990	468	0.902	177	1.253	60	1.381	0.929
1991	479	0.923	182	1.289	61	1.423	0.934
1992	514	0.950	201	1.302	62	1.433	0.941
1993	569	0.981	228	1.343	69	1.433	0.942
1994	622	1.007	248	1.377	73	1.453	0.961
1995	640	1.023	267	1.383	76	1.451	0.965
1996	665	1.038	273	1.388	78	1.454	0.968
1997	666	1.032	285	1.389	81	1.452	0.978
1998	665	1.047	291	1.383	86	1.457	0.988
1999	665	1.075	302	1.380	86	1.423	0.990
2000	661	1.025	293	1.364	92	1.412	0.989
2001	662	1.026	304	1.357	105	1.430	0.993
2002	656	1.001	311	1.339	108	1.448	0.972
2003	653	0.986	324	1.269	122	1.416	0.897
2004	655	1.024	348	1.290	130	1.412	0.945
2005	659	1.117	581	1.473	363	1.939	1.073
2006	659	1.129	586	1.480	368	1.936	1.072

Note: The balanced panel includes 259 cities. All regressions have good fit; most of the *p*-values for testing the null hypothesis $H_0 : \beta = 1$ are zeroes. Two cities (Lasa and Hailaer) have missing population data in various years and are not included in analysis.

In Table 1, the coefficient β in the third column is estimated using the full sample. The power exponent has been increasing from less than one in 1984 to quite greater than one in 2006, implying that the overall city size distribution becomes close to and finally more even than what Zipf's law predicts. In 19 out of 23 years an *F* test rejects the null hypothesis that β is equal to 1. Column 8 presents the Zipf's exponent for the balanced panel that includes 259 cities existing during 1984-2006. The pattern is very similar to the full sample, suggesting that the city sample of the balanced panel is representative.

Since many empirical studies confirm that the exponent is sensitive to the sample choice and is close to one for the upper tail of size distribution (Rosen and Resnick, 1980; Eeckhout, 2005), we also estimate the model by selecting only cities of size greater than a certain large threshold. The fifth and seventh columns report the results for cities of size greater than 200,000 and 500,000, respectively. The estimated power exponents now are significantly different from one, to be specific, significantly greater than one. The values of β increases when we move the cutoff to the upper tail, suggesting that larger cities distribute more evenly than what Zipf's law predicts. One possible explanation is that the Chinese government has implemented the policy that restricted the migration into large cities and promoted the development of small and medium-sized cities. Another explanation is that the current size distribution may not be in the steady state. In fact, the overall size distribution of Chinese cities has been evolving. According to the United Nations data source, in 2007 the urbanization rate in China is 42.2%, while the urbanization rate of developed countries is above 70%.[8]China is still in the period of rapid urbanization and the distribution of city sizes will keep evolving. Historically, the power exponent shows a U-shaped pattern in many countries (Parr, 1985). Cross-country studies also show that the Zipf's exponent is significantly different from one (Nitsch, 2005; Soo, 2005). In addition, using the Chinese city size data up to 1999, Anderson and Ge (2005) find that Chinese city sizes are better described by a log-normal distribution. Given all these pieces of mixed evidence, we tend not to make conclusion about the random growth and parallel growth by looking at only the evolution of the power exponent.

6.2 Non-stationarity in City Sizes

The sizes of a city at different time periods are most likely correlated due to reasons such as the durability of urban infrastructure, housing, and fixed costs of production. The intertemporal autocorrelation of city sizes implies that a temporary random shock to city size may have persistent impact on the future city growth. The random growth theory indicates that the growth of city size is a random walk, implying that a temporary shock

[8] In 2007, the urbanization rate of U.S. is 81.4%; Canada, 80.3%; Japan, 66.3%; United Kingdom, 89.9%; France; 77.1% (Source: World Urbanization Prospects: the 2007 Revision, available at www.un.org).

will have permanent effects on city growth. If a random shock is identified to have only temporary effects on city size, as in Davis and Weinstein (2002), then the random growth theory can be rejected.

Testing the persistence of a random shock to city size boils down to the test for the stationarity of city sizes or the test for unit roots. Let $\ln P_{it}$ denote the logarithm of the population of city *i* at time *t*, then, the simplest specification is to assume that city size is a first-order autoregressive (*AR*(1)) process:

$$\ln P_{it} = \phi_i \ln P_{i,t-1} + \varepsilon_{it},$$

where ϕ_i is the first-order autocorrelation coefficient and ε_{it} is the random shock at time *t*. The augmented Dickey-Fuller (ADF) test for non-stationarity (Dickey and Fuller, 1979) of population levels takes the form

$$\Delta \ln P_{it} = \gamma_i \ln P_{i,t-1} + \varepsilon_{it},$$

where $\gamma_i = \phi_i - 1$. The null hypothesis is non-stationarity: $\phi_i = 1$ (or $\gamma_i = 0$). If $\phi_i < 1$, city population will converge to a constant in the steady state. Since the conclusion of unit root test is sensitive to the specification of the model, we specify the model in the very general form, including a drift α_i and a linear trend $\beta_i t$ controlling for the upward trending:

$$\Delta \ln P_{it} = \alpha_i + \beta_i t + \gamma_i \ln P_{i,t-1} + \sum_{j=1}^{k_i} \rho_{ij} \Delta \ln P_{i,t-j} + \varepsilon_{it},$$

where k_i is the number of lagged difference term for city i .We choose the optimal lags using Bayesian information criterion (BIC).

To make sure the stationarity tests are reliable and robust, we also apply the KPSS test (Kwiatkowski et al., 1992). The null hypothesis of KPSS test is that the underlying time series is trend stationary, which is complementary to the ADF test. The KPSS test selects the optimal lag length automatically with Newey-West methodology. If the results from both ADF test and KPSS test agree with each other, then we will be confident about the stationarity characteristics of a city size.

Since China's economic reform and transition to a market economy may have had very different impacts on city size dynamics within different time periods, it is worth taking into account structural change or break point in the trajectory of city size. A methodology testing both unit root and endogenous structural break point simultaneously is the Zivot-Andrews (ZA) test (Zivot and Andrews, 1992). The null hypothesis of the ZA test is that the underlying time series $\ln P_{it}$ has a unit root with drift μ:

$$\ln P_{it} = \mu + \ln P_{i,t-1} + \varepsilon_{it}. \qquad (4)$$

The alternative hypothesis is that $\ln P_{it}$ is trend stationary with a one-time break in the trend occurring at an unknown point of time. For example, suppose that $\ln P_{it}$ has one structural change in the level, then, the regression equation for testing unit root is

$$\Delta \ln P_{it} = \mu + \theta DU_t(\lambda) + \beta t + \gamma \ln P_{i,t-1} + \sum_{j=1}^{k} \rho_j \Delta \ln P_{i,t-j} + \varepsilon_{it},$$

where $\lambda = t/T$ is the location of the break point and is chosen to give the least favorable result for the null hypothesis (4) and $DU_t(\lambda) = 1$ if $t > T\lambda$.[9] Again BIC is applied to select the optimal lag length in the ZA test.

Small sample size, especially short time period, is a notorious problem to the standard time series analysis, especially for the stationarity test and cointegration analysis. For example, severe size distortions are found in stationarity test when a time series has a large negative moving average (MA) root (Schwert, 1989) or a large AR root (DeJong et al., 1992). One possible remedy is to expand the time span of the data set. But we are aware that before 1981 China employed different definitions of urban population and it is very difficult to adjust the data to be consistent. To deal with the small sample size problem, we interpolate annual city size time series data and transform them into higher

[9] Similarly, if we assume that $\ln P_{it}$ has one structural change in the growth rate, then, the regression equation for testing unit root is $\Delta \ln P_{it} = \mu + \beta t + \theta DT_t(\lambda) + \gamma \ln P_{i,t-1} + \sum_{j=1}^{k} \rho_j \Delta \ln P_{i,t-j} + \varepsilon_{it}$, where $DT_t(\lambda) = t - T\lambda$ if $t > T\lambda$. We generally consider only the structural change in the level.

frequency—quarterly—data.[10] Of the two commonly used interpolation methods—the quadratic method and the cubic spline method, we use the second as recommended by Baxter (1998).

We select cities in the balanced panel from 1984 to 2006 but exclude cities at the county level to do the unit root tests.[11] Overall, both the ADF and KPSS tests show that 153 out of 210 cities have unit roots, suggesting that the sizes of most cities are not stationary. Table 2 reports the unit root test results for some selected cities: panel 1 presents the cases that the ADF test and KPSS test are not consistent, panel 2 the cases that are stationary, and panel 3 the cases that are not stationary. It is worth noting that in panels 2 and 3 when both ADF and KPSS tests agree with each other, the ZA test tends to be consistent too.

[10] Interpolation is commonly used in macroeconomics to transform low frequency data into high frequency data. For example, Bernanke, Gertler, and Watson (1997) interpolate quarterly GDP data into monthly series when studying the effects of monetary policy.

[11] Cities at the county level are in general small cities and the definition for city population changed since 2005.

Table 2

Testing stationarity of city sizes

City name	ADF test	KPSS test	ZA test	Break point date
Examples of cities with inconsistent testing results				
Anyang	-1.950	0.142	-5.413*	2002Q4
Baoji	-3.093	0.063	-3.934	1997Q4
Baotou	-2.595	0.078	-3.722	1989Q2
Binzhou	-2.081	0.095	-3.438	1999Q3
Examples of cities that are trend stationary				
Dazhou	-3.710*	0.142	-5.117*	1992Q4
Deyang	-3.850*	0.089	-4.245	1993Q3
Jingmen	-3.812*	0.067	-4.993*	1992Q4
Xiangfan	-4.240*	0.141	-7.361*	2003Q2
Examples of cities that are non-stationary				
Shanghai	-0.134	0.268*	-1.762	2003Q3
Beijing	-2.886	0.270*	-3.305	1990Q1
Chongqin	-0.463	0.272*	-1.394	1990Q2
Guangzhou	-2.008	0.235*	-8.171*	1999Q4

Note: For the ADF test, the null hypothesis is non-stationarity; the critical value for the 5% level is -3.46. For the KPSS test, the null hypothesis is trend stationarity; the critical value for the 5% level is 0.15. For the ZA test, the null hypothesis is non-stationarity without a break point and the alternative hypothesis is trend stationarity with an endogenous break point; the critical value for the 5% level is -4.80. Superscript "*" indicates significance least at the 5% level.

It is well known that the power of unit root test based on single equation is poor, especially when the time series is short. Panel unit root tests with a large *N* can improve the power. The time length of our data set is not very long; but the number of cities is large enough. For robustness check, for the 153 cities detected with unit root, we also conduct the Im-Pesaran-Shin panel unit root test (Im, Pesaran, and Shin, 2003) and the Levin-Lin-Chu panel unit root test (Levin, Lin, and Chu, 2002). Both test results can not reject the null hypothesis that all cities in the panel have unit roots (the values of Im-Pesaran-Shin test statistic and the Levin-Lin-Chu test statistic are 16.3 and 17.0, respectively).

We also conduct unit root tests for population growth rate of the same set of cities, using the first-order difference of logarithmic population level. The null hypothesis of unit root of growth rate is rejected for all cities.

Two inferences can be drawn from unit root tests. First, there exists no steady state size for

the majority of cities. This rejects the conditional convergence hypothesis. Second, since for the majority of cities, city size is a non-stationary process and the rate of growth is a stationary process, we can not reject the random urban growth theory as confidently as Davis and Weinstein (2002).

6.3 Testing parallel growth

Even city sizes evolve in a non-stationary way, they still could move together as city growth is affected by many common factors, such as national economic growth or other nation-wide macroeconomic factors. A special case is that cities grow parallel in the long run but deviate in the short run, which can be tested using equation (2). Parallel growth of cities also implies that their population levels move together with the national urban population.

Parallel growth among cities implies that city sizes are cointegrated with a cointegrating coefficient of 1 (γ=1 in equation (2)). While various methods of cointegration test, such as Johansen-Juselius cointegration rank test (Johansen and Juselius, 1990), are applicable here, a more convenient way is to test whether the logarithm of the ratio of two city sizes is stationary or not. To see this, suppose two city sizes grow parallel, then equation (2) can be re-written as

$$\ln(P_{it} / P_{jt}) = \alpha + \varepsilon_t , \qquad (5)$$

meaning that parallel growth of two cities requires that the ratio of two city sizes be stationary around a constant. Furthermore, if city *i* grows faster than city *j* by a constant rate, the relationship will be featured by a linear time trend:

$$\ln(P_{it} / P_{jt}) = \ln P_{it} - \ln P_{jt} = \alpha + \beta t + \varepsilon_t . \qquad (6)$$

We can apply the same unit root test techniques in section 6.2 to test whether the transformed time series data $\ln(P_{it} / P_{jt})$ is (trend) stationary. Another advantage of using equation (6) to test parallel growth is that we can take into account structural change in either or both cities under testing.

It would be unnecessary to compare by pair all cities that are non-stationary to detect the growth pattern. We first randomly select cities of same size, or of same region, or with same major government intervention (such as special economic zones) to test for parallel growth. Our preliminary finding is that the majority of cities do not appear to grow parallel; however, cities with the same location-specific characteristics, such as same region, same major natural resource endowment, and same policy intervention, are more likely to grow parallel. Therefore, as a representative demonstration, we present the results for 7 groups of cities with similar locational fundamentals: tourist cities, capital cities, coastal cities, cities in Yangtze River Delta region and Pearl River Delta region, and cities in Southwestern region and Northeastern region.

Table 3 provides the ADF, KPSS, and ZA test results for testing parallel growth for the 7 groups of cities. To save space, for each group, we present only three cities that grow parallel with the reference city of each group.

Table 3

Testing for parallel growth of city sizes

Cities	ADF	KPSS	ZA	Break point date
Group 1: Tourism cities (Guilin as reference city)				
Hangzhou	-1.165	0.270*	-7.029*	2000Q4
Suzhou	-0.976	0.253*	-6.945*	2000Q4
Xian	-4.024*	0.138	-5.518*	1994Q4
Group 2: Capital cities (Guangzhou as reference city)				
Beijing	-2.244	0.171*	-6.117*	2001Q2
Shanghai	-2.706	0.169*	-6.325*	1999Q4
Shenyang	-3.225	0.252*	-6.982*	1999Q3
Group 3: Coastal cities(Shantou as reference city)				
Sanya	-0.779	0.230*	-8.196*	2002Q3
Shenzhen	-0.797	0.257*	-6.413*	2002Q3
Xiamen	-0.977	0.182*	-8.189*	2002Q4
Group 4: Yangtze River Delta cities (Shanghai as reference city)				
Hangzhou	-0.0994	0.263*	-6.870*	2000Q3
Nantong	-1.417	0.148*	-6.013*	2002Q3
Suzhou	-0.832	0.243*	-6.389*	2000Q4
Group 5: Pearl River Delta cities (Jiangmen as reference city)				
Guangzhou	-2.503	0.165*	-5.550*	2002Q3
Shenzhen	-1.113	0.248*	-5.138*	2002Q1
Zhongshan	-1.236	0.187*	-8.363*	2001Q4
Group 6: Southwestern cities (Panzhihua as reference city)				
Chengdu	-0.768	0.253*	-6.451*	1989Q4
Leshan	-2.969	0.078	-5.488*	1998Q4
Mianyang	-2.293	0.190*	-5.539*	2002Q3
Group 7: Northeastern cities (Liaoyang as reference city)				
Anshan	-0.647	0.169*	-4.917*	1989Q4
Benxi	-1.536	0.159*	-4.956*	1993Q3
Fuxin	-1.174	0.145	-5.226*	1993Q3

Note: For the ADF test, the null hypothesis is non-stationarity; the critical value for the 5% level is -3.46. For the KPSS test, the null hypothesis is trend stationarity; the critical value for the 5% level is 0.15. For the ZA test, the null hypothesis is non-stationarity without a break point and the alternative hypothesis is trend stationarity with an endogenous break point; the critical value for the 5% level is -4.80. Superscript "*" indicates significance at least at the 5% level.

(1) Tourism cities. Obviously, tourism cities have location-specific fundamentals—natural tourist attractions such as beautiful lakes, rivers, beaches, and mountains. Using Guilin as the reference city, we conduct parallel growth test for the 54 cities in the first list of the best tourism cities nominated by the National Tourism Administration of China in 1998. Panel 1 of Table 3 reports the test statistics for three cities that grow parallel with Guilin. It is interesting to see that Hangzhou and Suzhou satisfy parallel growth condition with one level shift occurring at the same date (the second quarter in 2000). These two cities are geographic neighbors in Zhejiang province but Hangzhou is a capital city. Figure 1 plots the logarithm of population levels for Hangzhou, Suzhou, and Guilin. Visually we can see that the three cities grow parallel if we ignore the break point occurring in 2000 for Hangzhou and Suzhou. Figure 2 plots the logarithm of population ratio for Hangzhou and Suzhou compared with Guilin, and the patterns are remarkably similar. Taking together, we tentatively conclude that natural tourist attractions might play a very important role in long-run urban growth for tourism cities.

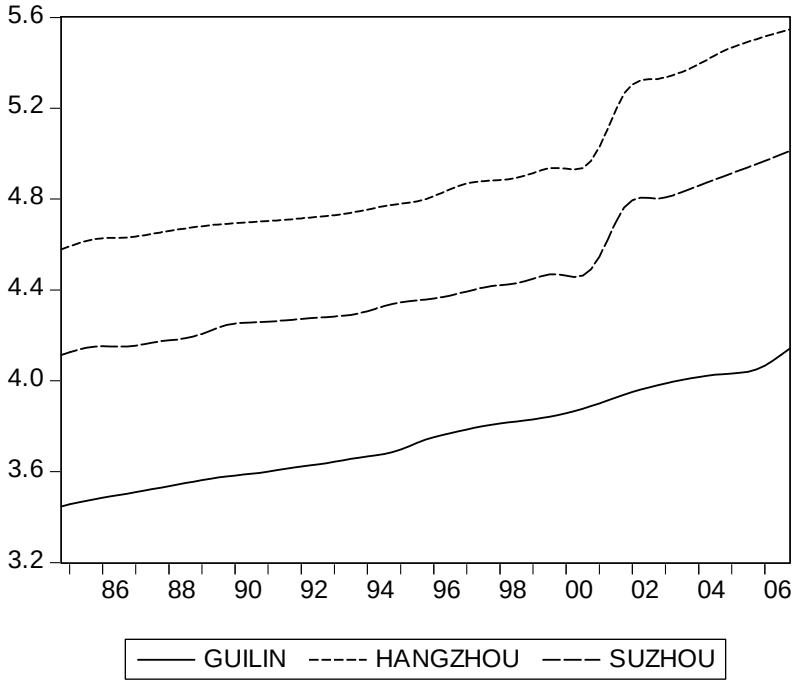

Figure 1 Population levels of three tourism cities

Note. The vertical axis is the logarithm of city population; the horizontal axis is year.

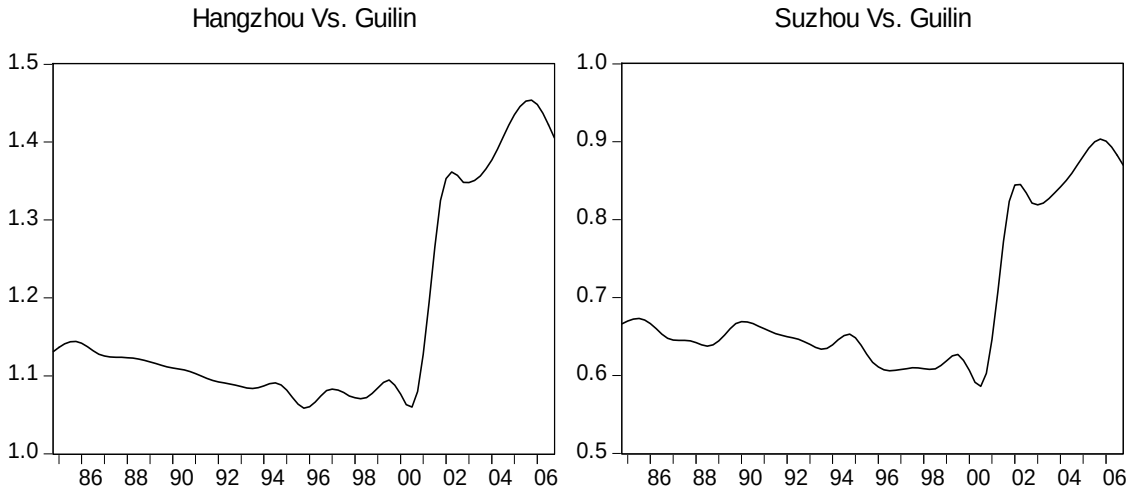

Figure 2 Logarithm of population ratio

Note. The vertical axis of the left panel is the logarithm of population ratio of Hangzhou to Guilin; the vertical axis of the right panel is the logarithm of population ratio of Suzhou to Guilin; the horizontal axis is year.

(2) Capital cities. A provincial capital city or a municipality directly under the central government can be considered a “policy city” in the sense that it receives all kinds of favorable economic policies and resource allocation from central and local governments, even more so during the planned economy period. If we treat location-specific policies as general location fundamentals, then, these capital cities have advantages comparable to natural tourist attractions in tourism cities. There are 32 capital cities in China. Using Guangzhou as the reference city, panel 2 of Table 3 shows that Beijing, Shanghai, and Shenyang grow parallel with Guangzhou.

(3) Coastal cities. Coastal cities are harbor cities and enjoy natural location advantage in transportation. They are also the cities that started transition in the early stage of China economic reform and have received favorable government intervention. Choosing Shantou as the reference city, panel 3 shows that Sanya, Shenzhen, and Xiamen grow parallel with Shantou. We should point out that Shantou, Shenzhen, and Xiamen are three of the five cities in the special economic zones.

(4) Yangtze River Delta cities. Cities in this region have both transportation advantage (near the Yangtze River and the Pacific Ocean) and policy advantage (receiving favorable open and reform policies); furthermore, this region is one of the manufacturing industry clusters. Panel 4 shows that Hangzhou, Nantong, and Suzhou grow parallel with Shanghai.

(5) Pearl River Delta cities. Cities in this area enjoy advantages similar to Yangtze River Delta cities. They also attract labor intensive manufacturing firms. Panel 5 shows that Guangzhou, Shenzhen, and Zhongshan grow parallel with Jiangmen.

(6) Southwestern cities. Southwestern cities are located in less developed Southwestern China, with less developed transportation network and a large minority population. Taking cities in Sichuan province as examples, panel 6 shows that Chengdu, Leshan, and Mianyang grow parallel with Panzhihua when a structural change is taken into account.

(7) Northeastern cities. Northeastern region is a traditional heavy industry center and a mining center. Panel 7 of Table 3 shows that Anshan, Benxi, and Fuxin grow parallel with Liaoyang conditional on a structural change. Anshan, Benxi and Liaoyang are well-known for their steel industry, and Fuxin is well-known for its coal mining industry. This panel suggests that natural resource endowment might play an important role in long run growth of "resource cities."

After examining the above seven groups of cities, we have found rare evidence for the simple, deterministic, parallel growth among Chinese cities. However, after taking into account growth trend and structural change in city size, we find some pairs of cities with common group characteristics do grow parallel in terms of generalized concept of parallel growth. Those common characteristics can be summarized as generalized locational fundamentals, including natural tourist attractions (tourist cities), transportation advantages (coastal cities), natural resource endowment such as coal mine (resource cities), and similar government interventions (policy cities). If we extend the definition of locational fundamentals to any location specific amenities, including natural resources, location

accessibility, and government interventions, the identified parallel growth patterns of sub-groups may partly support the locational fundamentals theory.

One point worth noting is that structural changes occur to the growth path of many cities. This is not surprising since transition to a market economy and rapid urbanization in China are accompanied by dramatic institutional changes and government interventions, such as the Western region development plan and favorable economics policies to the Pearl River Delta and Yangtze River Delta regions. Our research show that it is important to take into account structural changes when studying city size distribution and city size dynamics for developing countries.

7. Conclusions

Three urban growth theories, namely the endogenous growth theory, the random growth theory, and the hybrid growth theory, predict three types of parallel growth of cities—deterministic parallel growth, random growth with a stable steady-state distribution, and cointegrated parallel growth, respectively. This paper focuses on identifying the parallel growth patterns of Chinese cities based on these three urban growth theories. Given the fact that China is still in the period of rapid urbanization, even though we apply rigorous time series econometric techniques, we can only tentatively conclude that the overall Chinese city growth does not follow the pattern of simple, deterministic, parallel growth. However, once allowing for growth trend and structural change, we find that a small number of cities with certain common group characteristics, such as similar location advantages or policy regime, do grow parallel. For example, super large-sized cities Guangzhou and Shanghai grow parallel; steel industry cities Anshan and Liaoyang grow parallel; Shenzhen and Xiamen, both in special economic zones, also grow parallel. Our findings suggest that location fundamentals may have persistent impacts on urban growth. Furthermore, if we extend the concept of locational fundamentals to any location-specific factors, including natural resource endowment, transport accessibility, and government interventions, our findings provide some evidence supporting the locational fundamentals urban growth theory.

Our research focuses on only cities from the balanced panel (having observations since 1984). However, one of the striking features of Chinese urbanization is the entry of new cities each year. It would be interesting to investigate the growth evolution incorporating migration and the birth of new cities. In addition, we are only interested in identifying the growth pattern in this paper, but urban growth determinants warrant further studies.

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