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# Why Do Megacities Coexist with Small Towns? Historical Dependence in the Evolution of Urban Systems

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## Abstract

In a previous study, we have developed a spatial agent-based computational model in which migration dynamics generate Zipf's Law distribution of agents across locations. Building upon that work, here we aim to formalize the notion of path dependency in a city system where agents gravitate toward the sources of agglomeration economies. To that end, we develop a hybrid model in which discrete agents interact locally on a continuous space. This modification allows us to simulate large-scale urban systems with significantly greater levels of computational efficiency. The numerical results reveal path-dependent trajectories that generate multiple equilibria, each corresponding to a different initial condition. Specifically, we found a critical phase in which the entire population can either converge either to a giant mega city or to the highly-distributed Zipf's Law spatial pattern. The key parameter is the unit transport cost such that as it falls into a critical range, the model outcomes become indeterminate ex-ante. Our model produces these distinct spatial patterns under the same parameter values. Path dependence is thus the sole driving force determining the equilibrium spatial distribution. (***JEL*** **C63, R12**). *Keywords*: Spatial Agent Based Models; Zipf's Law.

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## I. Introduction

The defining character of a path dependent process is its stochastic feature. In particular, it is a stochastic dynamic process whose outcome depends on initial conditions as well as on random fluctuations over time. This dependency on initial conditions allows historical accidents to determine future outcomes: small fortuitous events drive virtually symmetrical beginnings into asymmetrical results. Over the course of history, the idea of path dependence seems to explain the formation of cities well. Bairoch (1988) chronicles places that had become dominant urban centers simply because small accidental events early on – early migrants' decision that coincide with others to settle in the same place – gave these places a head start. The presence of the early settlers then attracted the second wave of migrants who seek the benefits of being close to other migrants. The increasing concentration in turn renders these places even more attractive for the third wave of migrants, and so on.

In general, it is impossible to predict ex ante which locations would emerge as the leading cities, and what industries would thrive in them. Of course, certain locations possessing natural harbors or vicinity to rivers or lakes became urban centers due to their geographic comparative advantages. In today's information-driven modern economy, however, geographic advantages seem to hold less sway (see, e.g., Glaeser and Kohlhase, 2004). Instead, in an economy where increasing returns attract firms and workers to locations where resources already agglomerated, a small historical event can sustain further accumulations. Self-reinforcement then over time magnifies the effect of this small event, and ultimately determines whether locations become metropolises (large urban agglomerations), smaller towns, or supporting hinterlands.

The notion of path dependence has been applied to understand the dynamics of city formation (Arthur, 1994; Page, 1999). It has not, however, been applied to understand the tendency of urban settlements to self-organize into a hierarchical system of cities: the federation of geographically-distinct urban areas of various sizes that are inextricably linked with one another. The US city system, for example, contains two megacities with populations greater than 10 million according to the 2007 Census. Next in the hierarchy were seven large cities with populations less than 10 million but greater than 5 million. Following them were the 42 medium-size cities with populations less than 5 million but greater than 1 million. Still smaller were the 333 cities with populations greater than 1 million but greater than 100,000, and so on.

The most well-known stylized fact associated with many city systems across the world – including that of the US – is the Zipf's Law. The general statement of the law stipulates that if one ranks urban settlements according to the number of people who live in them, then the product of settlement *i*'s population raised to the power of *b*, $N_i^b$, and its population rank is equal to a constant for all cities:

$$Rank_i = \frac{C}{N_i^b}. \qquad (1)$$

When the power exponent $b$ = 1, The Zipf's Law is also known as the "rank-size rule," because it implies that settlements' populations are inversely proportional to their size rankings. One implication of the Zipf's Law is that if one ranks urban settlements in descending order according to population size – in the US case no. 1 corresponds to New York City, no. 2 to Los Angeles, and so on – and plots those ranks against population size, then one would get a relatively straight curve with slope very close to –1 and very high $R^2$ (see **Figure 1**).

[Figure 1 here]

The Zipf's Law describes an economy in which the population is distributed across cities such that a few megapolitans coexist with many medium-sized cities and even more numerous small towns. The Zipf's Law provides a good descriptive statistic for population distributions in many economies (see Rosen and Resnick, 1980; Soo, 2005). There are other types of population distribution, however, that have been observed in other economies. The largest US city (New York) is home to only six percent of its population but other economies, for example Argentina, Japan, and Mexico, have at least 20 percent of their population concentrated in a giant primate city (Ades and Glaeser, 1995). This study examines the role of past history in generating these different spatial patterns.

The population distribution of an urban system evolves as the result of individuals' autonomous decision to migrate. Modeling such a system therefore requires a bottom-up approach emphasizing the micro-behavior of individual agents to generate systemic macro-patterns such as the Zipf's Law. For our purpose, a computational model is more suitable than either a purely analytical or empirical approach. Unlike a purely analytical approach, a computational model does not have to adopt restrictive assumptions in order to produce closed-form solutions, which are virtually impossible to derive from our model because of non-linear and spatially-local interactions among agents. Computational models thus help the analysis of complex systems that otherwise are too complex to solve analytically. At the same time, a computational model is designed to focus only on key variables of interests, while controlling for others. Thus, unlike empirical approaches, a computational model does not suffer from identification problems.

In this paper, we propose the use of a hybrid computational agent-based model to link the emergence of the Zipf's Law to the path-dependence process of migration. The model was originally developed and presented in Shin et al. (forthcoming). The model has an explicit spatial component: at any given time every agent occupies a unique location. The computational model of Shin et al. (forthcoming) belongs to the hybrid class because discrete agents interact locally on a continuous space. The mechanics of the model is driven by the relative strengths of two opposing forces: the agglomeration effect of increasing returns and the dispersion effect of moving costs. On one hand, increasing returns create a positive feedback loop: the more agents chose a particular location, the more attractive it becomes for future migrants. Moving costs on the other hand mitigate the attractiveness of faraway locations.

At one extreme where transportation is prohibitively expensive, the initial distribution of fragmented, small-scale settlements is preserved. The strength of the dispersion force diminishes as transport cost falls. Thus at the other extreme where the agglomeration force is considerably stronger, the entire population of agents converges to single, giant city. In between these two extremes, the reduction of transport cost typically results in a mix system where large cities coexist with small towns. The impact of lower transport cost, however, is highly non-linear. Starting with prohibitively high transport cost, a weakening of the dispersion force initially is accompanied by a gradual increase in the size of the largest cluster, which indicates the birth of a megacity. There is a threshold level, however, at which the size of the largest cluster suddenly jumped up even when transport cost falls only marginally. It is at the slightly lower levels of transport cost than the threshold that multiple equilibria begin to emerge.

In this critical region of multiple equilibria, the model outcomes were not predictable ex-ante. Distinct initial conditions can generate various spatial distributions under the same set of parameter values. Specifically, the agent population can converge into a single location or distributed into multiple clusters of various sizes depending only on minor differences in the initial distribution of agents. Path dependence thus introduces indeterminacy in the form of multiple equilibria: small coincidental events in the beginning – the uncoordinated decisions by first migrants to settle in the same place – were magnified by the agglomeration force as to determine the final outcome.

In contrast to path dependent studies that focus on specific outcomes (see, e.g., Arthur, 1989; David, 1985), this paper examines the long-run spatial distribution of population that emerges from a dynamic process characterized by increasing returns. That is, rather than asking why Chicago became the great hub of the Midwest instead of St. Louis, we ask why the Zipf's Law became the defining statistic of the US city system instead of, say, a high concentration of population in the primate city as would be appropriate in, e.g., Argentina, Japan, Mexico, and Uruguay.

The rest of the paper is structured as follows. We review the relevant literature in the next Section II, and detail the model in section III. Section IV presents the numerical results. We close in Section V with concluding remarks.

## II. Literature Review

There is a massive body of empirical studies establishing the prevalence of the Zipf's Law across countries. It was Auerbach (1913) who first observed the rank-size in the distribution of cities. The widespread presence of this empirical regularity in other domains outside urban systems, however, did not receive greater recognition until the seminal publication of Zipf (1949), to whom the "law" was credited. The empirical regularity, though striking, early on was viewed as irrelevant due to the lack of understanding of the socioeconomic drivers. Christaller (1933) for example belittled Auerbach's finding as "nothing more than just playing with numbers," while Hoyt (1951) derided Zipf's Law as a formula that "would conceal the real problems under the masquerade of mathematical symbols."

Theoretical studies that been advanced to explain the mechanisms leading to the emergence of the Zipf's Law remain scarce. The class of random-growth models that Simon (1955) pioneered relies on preferential attachment mechanism to generate the Zipf's Law. Gabaix (1999) provides a recent restatement of Simon's original contribution. Within this class of models, a newly-arriving agent permanently attaches itself to the location that it chooses at the beginning. These models therefore are not suitable for in which people often change their locations at different stages of their life cycles. Recent contributions have emphasized the microfoundations of the Zipf's Law. For example, Eaton and Eckstein (1997) propose a model of utility maximizing agents that choose locations in which their expected lifetime earnings are highest. As in Simon's random growth model, however, a newly arriving agent in their model also attaches itself permanently to its initial choice of location.

In the new economic geography literature, there is a growing acceptance for numerical methods as a robust analytical tool to examine the spatial concentration of economic activities in certain locations.[2] In particular, a class of numerical models known as computational agent-based model has been utilized extensively to examine complex social systems – systems of interacting agents whose individual behavior lead to the emergence of large scale, aggregate patterns (Holland and Miller, 1991). In the context of our study here, the individual behavior corresponds to migratory behavior while the emerging aggregate pattern to the Zipf's Law.

[2] Fujita et al. (1999) provides an early review of the literature.

Computational models have been increasingly relied upon to examine the mechanics of population distribution in a system of cities. The latest contributions include Mansury and Gulyas (2007) and Shin et al. (forthcoming), both of which employ an agent-based model to generate the Zipf's Law spatial distribution of the population across cities. The main differences between the numerical model of Mansury and Gulyas (2007) and ours [developed in Shin et al. (forthcoming)] are as follows. For brevity, in what follows we shall simply refer to the model of Shin et al. (forthcoming) as "our model" here. First, in contrast to their model in which agents differ due to their different mobility, in our model here we have identical agents with the same mobility level. In addition, explicit consideration of spatial constraint is a key feature of our model here. Specifically, in our model a location can only be occupied by at most one agent. In effect, every location in our model has a maximum carrying capacity of 1. As a result, the territorial area of a city is directly proportional to that city's population. This is not the case in Mansury and Gulyas (2007) where any location can accommodate an unlimited number of agents (i.e., infinite carrying capacity). We believe that our model captures the spatial feature of a city in a more realistic way.

## Path dependence

During its early conception, path dependence refers to accidental events whose impact in the beginning appear to be trivial, but over time are propagated and magnified so that they eventually become the decisive factor determining the ultimate outcome (see David, 1985). The urban economics literature is littered with success stories of locations that through sheer luck become today's vibrant cities. Cronon (1991) for example chronicled the history of Chicago that developed as a transport hub facilitating the shipment of grain, lumber, and cattle from the hinterland to the east coast.

It was the seminal paper of Arthur (1989) that brought into spotlight the recognition of multiple equilibria due to historical small events that over time were magnified by increasing returns. For our purpose here, the spatial dynamics of the population in a system of cities exhibit path dependence when the current distribution depends on the population distribution in the previous periods:

$$\Gamma\left[ n_i(t+1) \right] = f\left[ \Gamma\left(n_i(t)\right) \right]. \qquad (2)$$

Following Page (2006), we shall also distinguish between population dynamics in which the emerging distribution in a *specific period* is path dependent (*transitory path dependence*), and those in which the *equilibrium distribution* is path dependent (*equilibrium path dependence*). The former refers to the case in which the current distribution depends on past realizations, while the latter to the case in which the long-run distribution depends on past realizations.

## III. The Model

The model that we present here is originally developed and presented in Shin et al. (forthcoming). In what follows, we shall simply refer to the model of Shin et al. (forthcoming) as "our model" here. Two main effects drive the mechanics of our highly parsimonious model of two equations. The first is the "increasing returns effect" [or positive agglomeration effect] that describes the tendency for agents to locate in high-density places, ceteris paribus. The second is “transport-cost effect,” which reflects the fact that migration is a costly endeavor. The first effect encourages geographic concentration, while the second discourages it. If the “increasing-returns effect” – what we term the agglomeration force – significantly outweighs the “transport-cost effect” – what we term the dispersion force – then any initial advantage will trigger a self-reinforcing cycle of migration that ultimately results in a single giant city absorbing all agents. By contrast, if the transport cost is prohibitively high, then the initial distribution will be preserved since agents have little incentive to move. When the agglomeration and the dispersion forces are more or less balanced the typical result is a distributive system in which large megapolises coexist with medium cities and small towns.

Since at the moment the manuscript of Shin et al. (forthcoming) is still in press, it is useful to present the model in detail here. Consider a population of $M$ agents that are spatially distributed on a two-dimensional plane, whose edges are connected by periodic boundaries. The number of agents residing in the $i^{th}$ location corresponds to that location’s population size, $m_i$. We assume that the geometry of a cluster is a circle whose area equals its size: $\pi r_i^2 = m_i$. This assumption will prove useful later in simplifying the algebra when we consider the merging of two or more clusters.

When deciding where to locate, an agent assesses the attractiveness of location i using the following equation:

$$\phi_i = \phi_0(m_i) + \sum_{j=1,\, j\neq i}^{N} m_j / (D_{ij})^{\delta} \tag{3}$$

The first term corresponds to *increasing returns* [or positive agglomeration effect]: the more agents choose a particular location to be their migration destination, the more attractive that location becomes. It captures the spillover of knowledge among residents in the same city. To calculate the own-location's attractiveness, consider the typical resident A of city *i* who resides at the city's edge (see **Figure 2**).

[Figure 2 here]

Let $\rho_{Aj}$ be the distance between resident A and her fellow resident *j* of the same city. We calculate the own-city attractiveness as the distance-adjusted sum over all the city's population $m_i$:

$$\phi_0 = \sum_{j=1,\, j\neq A}^{m_i} 1/(\rho_{Aj}), \tag{4}$$

which can be approximated as

$$\phi_0 = \int_{m_i} dm/\rho = 4r_i = 4\sqrt{m_i/\pi}\ . \tag{5}$$

To see this, first convert into polar coordinates to obtain:

$$\int_{m_i} dm/\rho = \int_{\theta=-\pi/2}^{\pi/2} \int_{\rho=0}^{2r_i \cos\theta} \rho \, dr \, d\theta/\rho = 4r_i \,. \tag{6}$$

Since by assumption $\pi r_i^2 = m_i$, the last equality follows. Alternatively, if we assume instead that a typical resident lives at the city's *center*, then the own-city's attractiveness can be approximated as:

$$\phi_0 = \int_{m_i} dm/\rho = 2\pi\sqrt{m_i/\pi} = 6.28\sqrt{m_i/\pi} \,. \tag{7}$$

To see this, again convert into polar coordinates to obtain:

$$\int_{m_i} dm/\rho = \int_{\theta=0}^{2\pi} \int_{\rho=0}^{r_i} \rho \, dr \, d\theta/\rho = 2\pi r_i \,. \tag{8}$$

We can generalize the functional form of the own-city spillover effect as follows:

$$\phi_0(m_i) = c\sqrt{m_i/\pi} \,, \tag{9}$$

where $c$ is a constant such that $4 \le c \le 2\pi$. That is, we can impose different values of $c$ depending on our assumption regarding the location of the typical agent inside a city. The closer $c$ is to $2\pi$, the more benefit is assumed by aggregation in the sense that the importance of intra-city component increases relative to the intercity component.

The first term can be viewed as reflecting the location decisions of firms that seek to take advantage of agglomeration economies (see, e.g., Ellison and Glaeser, 1997). The population dynamics exhibit *increasing returns* since after having been selected once as a migration destination, the attractiveness of a city increases, which in turn increases its likelihood to be selected again in subsequent periods. There is a large body of literature examining the sources of agglomeration economies. For example, Murphy et al. (1989) and Krugman (1991) have argued that geographic concentration of firms confers increasing returns through the low transport costs, which enable firms to access both their consumers and suppliers more cheaply than otherwise. Glaeser et al. (1992) suggest that knowledge spillovers raise the average productivity of all firms in close proximity and hence reinforce agglomeration further.

Empirically, Henderson (1986) shows that indeed productivity is higher in places where same-industry firms cluster. Further, the extent of knowledge spillovers depends on the available stock of previously-accumulated knowledge (Henderson et al., 1995). Since a large pool of skilled workers – a proxy for knowledge stock levels – increase the productivity (and hence wages) of all workers (Moretti, 2004), the concentration of such workers in cities attracts further inflows of talented migrants. In this way, knowledge-based economies sustain both economic and population growth.

Moretti, Enrico. 2004. Estimating the social return to higher education: evidence from longitudinal and repeated cross-sectional data. *Journal of Econometrics*, 121: 175-212.

The second term captures the contribution of other inhabited (non-empty) locations in the system, distance adjusted by the denominator $D_{ij}^{\delta}$: the center-to-center distance between two locations, i and j, raised to the power of $\delta \geq 0$. Thus, other things equal, a strictly positive δ implies that nearby locations exert greater influence than those farther away. This term can be thought of as capturing the spillover of knowledge between cities, or the relocation of people from a metropolis to its suburbs (see Rosenthal and Strange, 2001). It is the spillover effects from neighboring cities lead to the formation of suburban enclaves that Garreau terms “Edge Cities” (1991).

An agent would migrate from city *B* to city *A* if the attractiveness gap between the two locations exceeds the transport cost:

$$\phi_A - \phi_B \geq f \cdot d_{AB}, \tag{10}$$

where *f* denotes the unit transport cost that is fixed for all agents, and $d_{AB}$ the shortest distance between location *A* and *B* defined as $d_{AB} = D_{AB} - r_A - r_B$.

Now we are ready to state the equilibrium condition. The system of cities is in equilibrium when for any two locations *A* and *B*, no agent in the system finds Eq. (10) to be true:

**Definition**. The system is in equilibrium when the stationary spatial distribution $\Gamma\left[M(t+1)\right]=\Gamma\left[M(t)\right]$ for all $t$ implies $\phi_A - \phi_B < f \cdot d_{AB}$ for every agent in the system and for any two locations $A$ and $B$.

## IV. Results

We report here numerical results from the simulations of a closed-system containing a total population of $M$ = 100,000 agents. At the beginning of every simulation, we distribute these agents uniformly randomly on a two-dimensional square plane of side length $L$. The plane's edges are connected by periodic boundaries that weld locations on opposite ends. Given total population $M$ and the plane area $L^2$, the average density of the system is $p = M/L^2$. Our main parameter of interest here is the transport-cost factor $f$. Note that the pair of parameters $p$ and $f$ fully describes the system configuration.

In any subsequent iteration, two cities are randomly selected. If **Eq. (10)** is satisfied, an agent in city $B$ migrates to $A$. Else, no action takes place. The matching-testing-moving sequence repeats until no further movement is possible throughout the entire system. The center of a city remains fixed in space, except for the case when two cities merge. When cities grow in size, their areas also expand and as a result the borders of a city might overlap with those of its neighboring cities. When the minimum distance between two cities falls to less than 1.0, a merger takes place. In this case, the center of the consolidated city is defined as the center of the mass of the two merging cities.

To illustrate how transport cost affects the equilibrium distribution of the population, **Figure 3** shows how the system evolves dynamically at different *f*-values. The upper series [**Figure 3** (a)] shows that at relatively higher transport cost, the system converges into an equilibrium distribution of a few mid-size cities that coexist with a multitude of small towns and villages. The middle figures also show that cities expand by absorbing the population from the neighboring locations, which leads to the white (empty) circles surrounding the cities. In contrast, at significantly lower transport cost [**Figure 3** (b)] the entire population ultimately converge to single location, which we term the "giant-city" outcome for convenience.

[Figure 3 here]

**Figure 4** plots the size of the largest city in equilibrium, $\overline{m}_{\max}$, for various levels of the unit transport cost *f*, and compare them across different population density *p*. Every observation in that figure corresponds to the average maximum size over 20 simulations, each with a different random seed. As expected, the plot exhibits an inverse relationship: higher transport cost is associated with smaller size of the largest city, and vice versa. Unexpectedly, however, there appears to be a threshold level of transport cost such that – when f is reduced further – the size of the largest city dramatically increases even though transport cost falls only gradually.

[Figure 4 here]

As we will show below, this threshold level of transport cost is critical in generating distinct stationary spatial distributions. The threshold level demarcates a critical region in which under identical set of parameter values p and f, the system can sometimes lead to the Zipf's Law distribution in which megacities coexist with small towns, some other times to an exclusive club of megacities, and in yet another times to a single giant city. The instability of the stationary distribution thus yields multiple equilibria, each corresponding to a different initial condition. In the physics literature, such an abrupt behavioral shift despite marginal change in parameter values is referred to as a "phase transition with symmetry breaking" (Nicolis and Prigogine, 1977). In the context of this study, the critical region is symmetry breaking because, starting from statistically identical distributions (uniform), the system nevertheless can end up at very different stationary distributions.

## Phase transition in the super critical state

Phase transition can be thought of as a system that is on the *brink of instability*: increasing the friction factor leads to stable system of uniformly-distributed cities, while decreasing the friction factor leads to a single basin of attraction whereby the entire population converge into a single giant city. In between is a range of mixed distributions – including the Zipf's Law – describing the coexistence of large cities with medium and smaller towns. History is the only thing that matters – different initial conditions lead to different equilibrium outcome – hence pure path dependencies of the system.

**Figure 5** shows how the typical equilibrium distribution changes as transport cost falls. When transport cost is prohibitively high, the system is in the sub-critical state where the population remains uniformly distributed across locations, or becomes a system of small clusters and isolated settlements associated with an exponential distribution. Figure 1 (a) shows an example of the latter. At this sub-critical state, the system never converges to a single giant city, a club of megacities ("oligarchs"), or to the Zipf's Law distribution.

[Figure 5 here]

The critical region is where "historical dependence rules." Under the same set of parameter, the system can converge to distinct equilibrium pattern depending solely on initial conditions. One critical region is the case where $f = 0.84$. We ran 100 simulations of this case under different initial conditions but identical parameter values. The results are as follows:

Single giant city: 7 cases

Oligarchs: 6 cases

Zipf's Law distribution: the rest of the 87 cases.

Thus, in the critical region the city system generates multiple equilibria. In particular, our model produces distinct spatial patterns under different initial conditions, while holding constant the parameter values. Path dependence is thus the sole driving force determining the equilibrium spatial distribution.

## V. Discussions and Conclusions

We propose in this study the use of a hybrid model capable of generating the Zipf's Law as an outcome of a pure path-dependence process. The model is originally presented in Shin et al. (forthcoming). The model's simulation results can explain why the dynamic trajectories of virtually-identical locations can diverge substantially. For example, Cronon chronicled the history of Chicago and St. Louis that were both initially poised to become the major urban hub of America's Midwest. But only one of them – Chicago – surged to become the dominant hub.

The model can successfully generate the spatial pattern of the Zipf's Law due to the migratory behavior of autonomous agents that gravitate toward the sources of agglomeration economies. Equilibrium becomes indeterminate (see, e.g., Matsuyama, 1991) when the presence of positive externalities magnify small, initially fortuitous events to eventually determine the final location of cities. In our model, such a fortuitous event occurs during the initial settlements when due to random chance, a few locations were "lucky" enough to be occupied by more than one agent, thus creating early agglomeration economies that in subsequent periods attract further inflows of migrants. Such path-dependent trajectory leads to a multiplicity of equilibria, each corresponding to a different initial spatial configuration of agents.

An interesting recent trend to examine is the rising concentration of population in large American cities. One way to track the extent of population concentration is by monitoring the Zipf's coefficient $b$ [see Eq. (1)]. A rising Zipf's coefficient over time suggests a tendency for the population to disperse more evenly in the geographic sense, vice versa a falling coefficient suggests a tendency for greater concentration. In the US case, **Table 1** reveals that between 2000 and 2007 the Zipf's coefficient has declined persistently, suggesting a trend of increasing concentration in larger cities that has continued until today.

[Table 1 here]

The model offers two alternative explanations – not necessarily mutually exclusive – for this increasing concentration. One possibility is that declining transport costs have resulted in greater concentration of population in large cities. The costs of moving tangible goods across locations in the US declined by more than 90 percent during the last century, and the trend has continued to the present (Glaeser and Kohlhase, 2004). Our model predicts an increasing concentration of people in large agglomerations as unit transport cost $f$ declines.

Pure path dependence could also result in increasing concentration due to a series of small random events that have *nothing* to do with transport costs. As our results demonstrate, even under identical parameter values, the system can yield distinct equilibrium spatial patterns when unit transport cost falls into the critical region. This suggests a stochastic trend corresponding to unit-root process in the evolution of the Zipf's coefficient. Whether the time series of the US population concentration can be described by a stochastic (pure path dependence) or a fixed time trend (declining transport costs) is the subject of a future empirical study. For now, we simply note that these two alternative explanations are observationally equivalent (see Perron, 1989).

In summary, in this study we have proposed a spatial model of migratory agents to model historical dependence that – among other equilibria – leads to the spatial distribution of the Zipf's Law. The model is originally developed in Shin et al. (forthcoming). Specific features of the model include hybrid approach treating space as a continuum variable, externality-driven migration, and limited mobility due to transportation costs. Future questions that could be addressed within this framework include whether the path dependencies are irreversible, the robustness of path dependencies, and the incorporation of forward-looking behavior. The last issue in particular is critical because migration is driven not only by how many people already chose to live in the destination locations, but also by expectations about how many people follow their footsteps in subsequent periods. This is especially true in the early settlements when differences in population size are insignificant, in which case expectations about future newcomers weigh heavily in migration decisions.

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# Figures and Tables

**Figure 1**. Plot of size rankings against population size, US metropolitan areas, 1997.

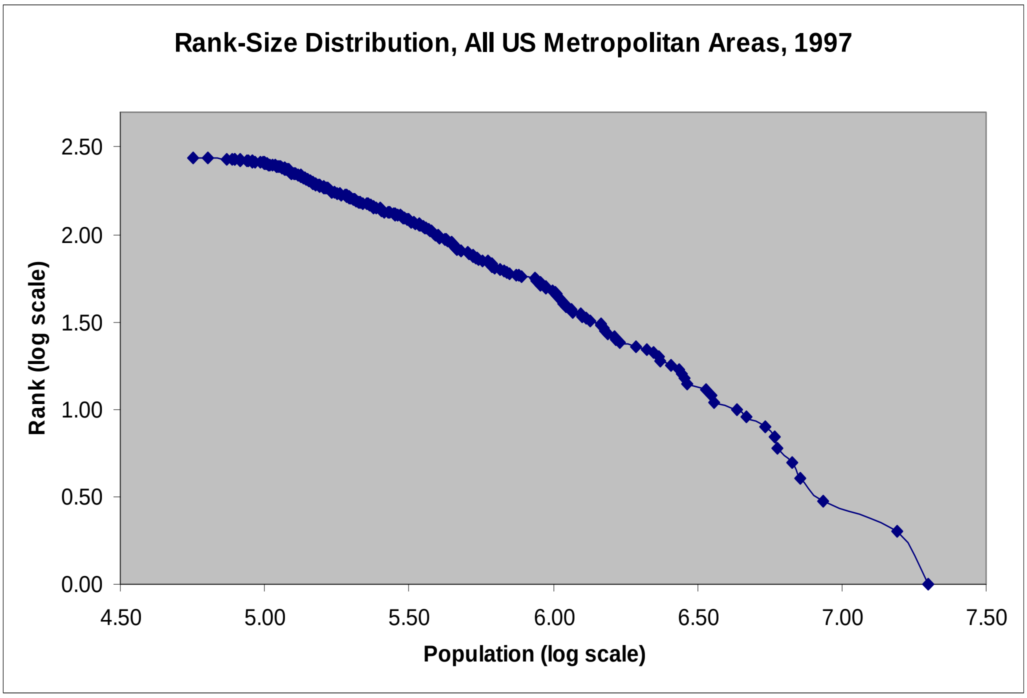



**Figure 2**. Distance between a city's typical residence and her fellow resident.

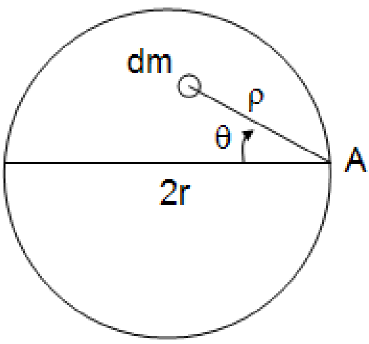
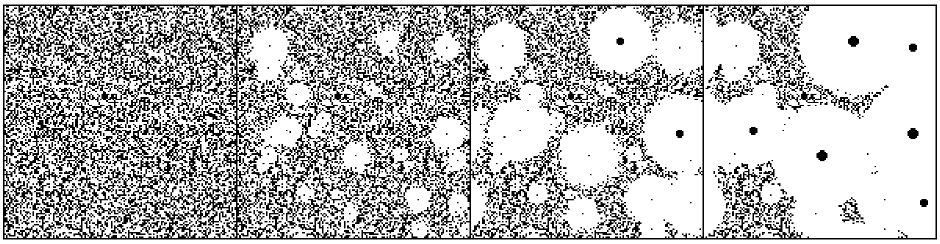
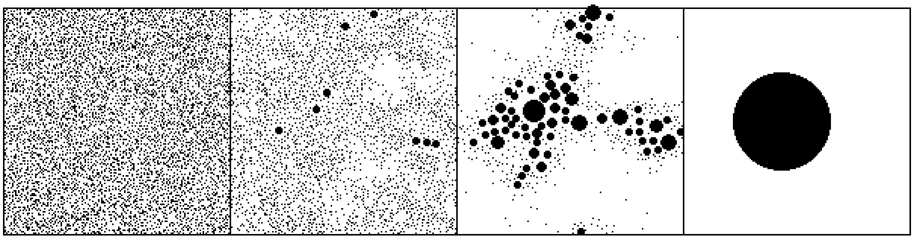


**Figure 3**. Typical evolutions of the population's spatial distribution at different friction factors.



(a) $p = 0.01$, $f = 0.35$.



(b) $p = 0.15$, $f = 0.10$.

**Figure 4**. Average size of largest city in equilibrium vs. friction factor *f*, various population density *p*.

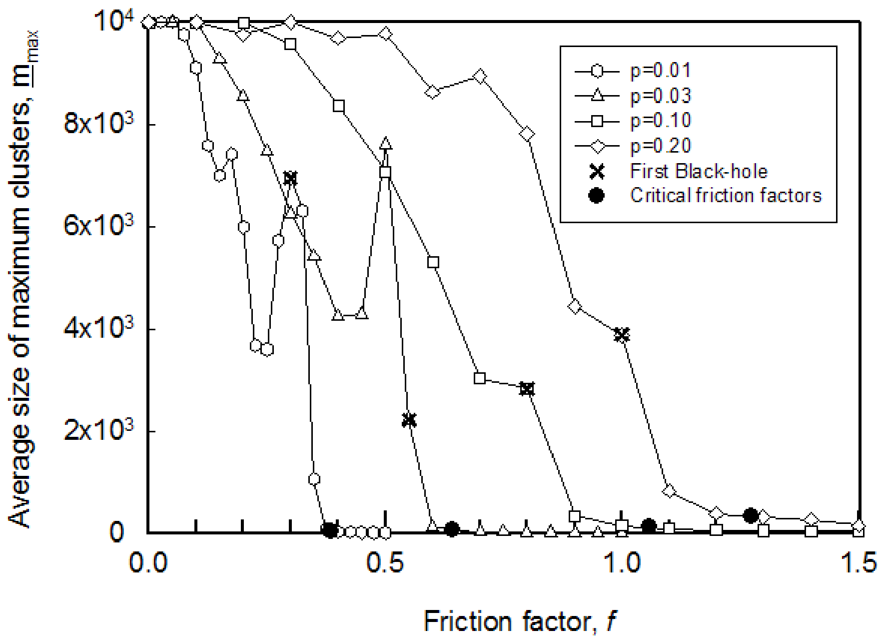


**Figure 5**. Equilibrium spatial distributions, various friction factors, $p$ = 0.01.

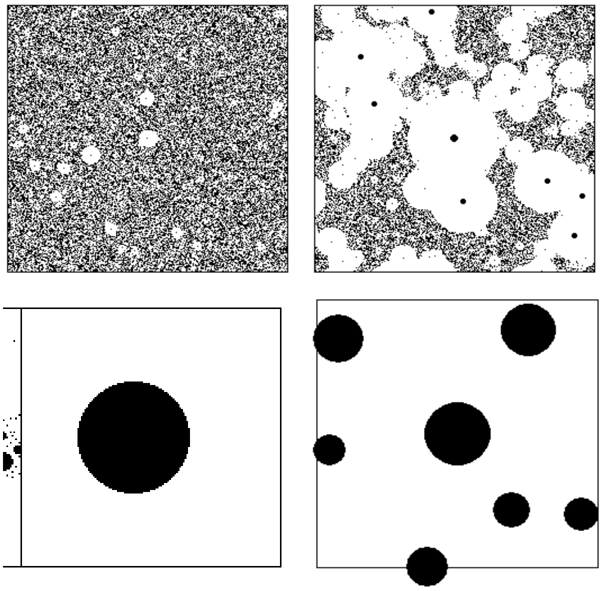


**Table 1**. The evolution of the Zipf's coefficient in the US metropolitan areas, 2000 - 2007.

| **Year** | **Zipf's Coefficient** | $R^2$ |
|---|---|---|
| 2000 | – 0.8167 | 0.9769 |
| 2003 | – 0.8080 | 0.9758 |
| 2005 | – 0.8029 | 0.9749 |
| 2007 | – 0.7992 | 0.9744 |

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