



## Scaling of prosocial behavior in cities

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### ABSTRACT

Previous research has examined how various behaviors scale in cities in relation to their population sizes. Behavior related to innovation and productivity has been found to increase per capita as the size of the city increases, a phenomenon known as superlinear scaling. Criminal behavior has also been found to scale superlinearly. Here we examine a variety of prosocial behaviors (e.g., voting and organ donation), which also would be presumed to be categorized into a single class of scaling with population. We find that, unlike productivity and innovation, prosocial behaviors do not scale in a unified manner. We argue how this might be due to the nature of interactions that are distinct for different prosocial behaviors.

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### 1. Introduction

It has recently been shown that cities conform to scaling relationships, analogous to living things. Kleiber's Law, an allometric scaling relationship that delineates the sublinear relationship between species mass and metabolic rate in mammals, was developed nearly a hundred years ago [1]. This relationship was found to conform to a power law, with the exponent  $\alpha$  of 0.75, where  $B$  is metabolic rate and  $M$  is organismal mass [2]:

$$B \propto M^\alpha.$$

Cities, which have long been thought to have organic properties (metaphorically and literally), can also be examined for scaling relationships, where urban population size is the equivalent of organismal mass. For a quantity  $A$ , the following relationship can be examined, where population of size  $N$  is raised to an exponent, and examined to see if the exponent is above, below, or at one:

$$A \propto N^\alpha.$$

The sublinear scaling in organisms has been explained to be a result of the fractal branching of structures within living things, such as the circulatory system [2]. Certain quantities within cities, especially those related to economies of scale, such as the number of gas stations per capita, also scale sublinearly relative to urban population size, albeit for different underlying reasons [3].

However, other sociological quantities instead typically obey a superlinear relationship. For economic productivity and creative output within cities, it was found that the larger the population size of the metropolitan area, the greater these quantities per capita, with exponents found to cluster between 1 and 1.5, with the mean around 1.2 [3]. The superlinear scaling in productivity and innovation can be explained by the structure of collaborative ties within an urban social network [4].

While productivity and innovation have been shown to obey superlinear scaling, it is not known whether or not prosocial behavior obeys a similar pattern. Prosocial behavior is "good" behavior which promotes social well-being. This can range from being altruistic (volunteering), being generous (such as giving money or blood), voting, or other similar behaviors.

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Prosocial behavior is a key predicate for the formation and operation of social networks, a fact that is only recently beginning to draw the attention of network scientists, social scientists, biologists, and philosophers [5,6]. If people never behaved generously or altruistically towards one other, never reciprocated kind behavior, or, worse, were always violent towards one another, then social ties would dissolve and the network around us would disintegrate [5]. Some degree of prosocial behavior is therefore crucial for the emergence and endurance of social networks. Moreover, once networks are established, prosocial acts – from random acts of kindness to a cascade of organ donation – can spread through them.

Since social networks can exhibit positive feedback cascades of any behavior, including prosocial behavior, it is natural to assume that prosocial behaviors should scale superlinearly with population size of a city. Or, in any case, they should scale faster than anti-social behaviors, otherwise agglomerations of people would become unsustainable. When antisocial behavior has been examined, in the form of crime, it has been found to scale superlinearly, similar to productivity and innovation [3]. If larger networks (which offered more opportunities for interaction) fostered increases in violence more rapidly than, say, increases in kindness, city growth would be constrained in a fundamental way.

Past work provides evidence for gross differences in prosocial behavior based on population size, but no one has examined the quantitative scaling of metropolitan areas for a variety of prosocial behaviors. For example, Milgram's lost-letter technique [7] can be used to tease out differences in altruistic behavior between populations, since the very act of returning a lost letter is itself an altruistic act, and the percentage of returned letters can be used as a measure of prosocial behavior [8]. Some of the lost-letter literature finds that lost letters are returned at a higher rate in cities than in suburbs, and higher in turn than in small towns [9,10]. In addition, research has shown that city size is significantly correlated with the prosocial behavior of tolerance [11]. Others, however, find little variation in regional population size [8]. Similarly, Glaeser and Gottlieb find that population density is uncorrelated with social capital [12]. In contrast, Milgram showed that willingness to trust and assist strangers is greater in small towns than in large cities [13]. A meta-analysis finds that there is a decline in this type of prosocial behavior with an increase in city size, beginning with cities of a population greater than 300,000 [14].

Using a variety of datasets for prosocial behavior coded by metropolitan area, we find that prosocial behavior is different than productivity and innovation and does not adhere to a specific class of scaling relationship. We argue that the many components of these prosocial behaviors – locality and feedback – might explain the variety of empirical relationships found for prosocial behaviors.

## 2. Data and methods

We examine a variety of prosocial behaviors in the United States, as well as antisocial behaviors, for comparison. The data were assessed at the level of core based statistical area (CBSA), areas defined by the United States Census, which include both metropolitan and micropolitan regions. Over 900 CBSA's were included in each analysis. United States Census data were used to determine population size and density to test for scaling.

### 2.1. Political contributions

We examined the number of contributions to presidential campaigns by CBSA, as well as the total dollar amounts given by each CBSA for the 2008 Presidential campaign. This data were obtained from the Federal Election Commission [15].

### 2.2. Voting

We examined the total number of votes for president by CBSA in the 2004 general election. These data were obtained from the Federal Elections Project at American University.

### 2.3. Organ donation

We examined the number of organs donated by deceased individuals and living individuals for the years 1995–2008 from the United Network for Organ Sharing, based on Organ Procurement and Transplantation Network data. CBSA population from 2001 was used to test for scaling, as it is the intermediate year.

### 2.4. Census mail responses

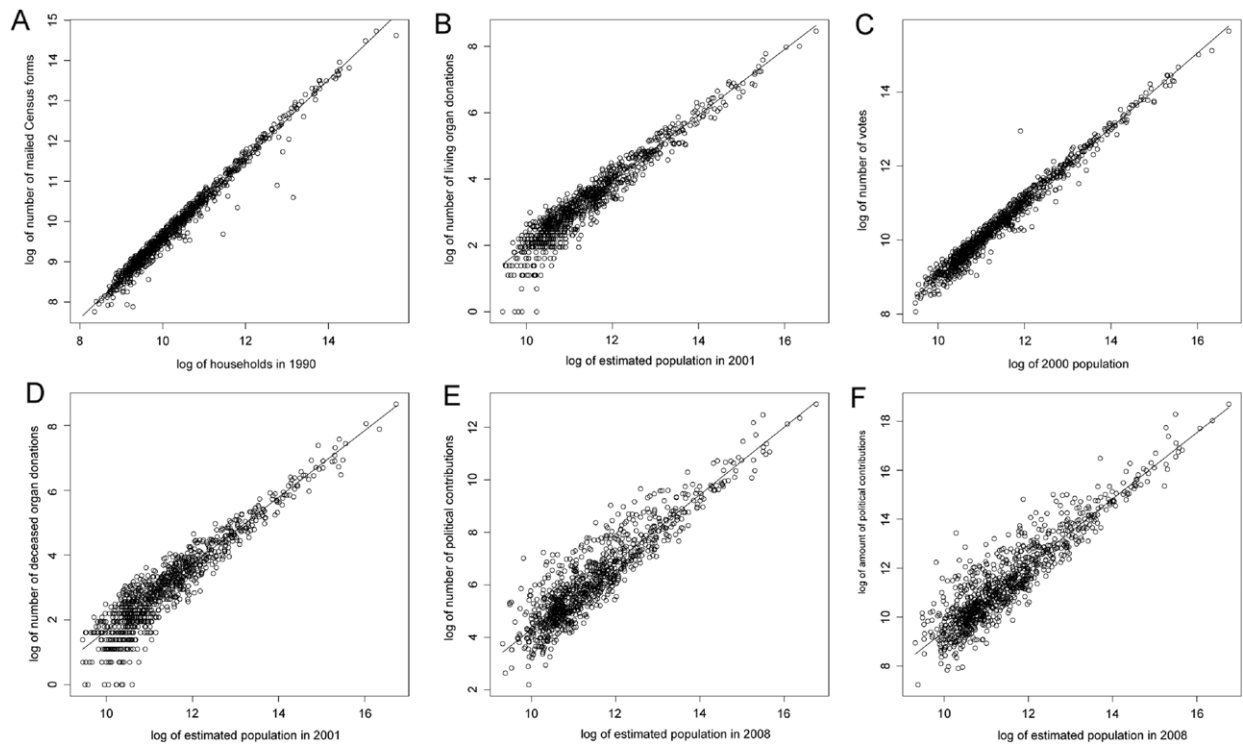
The United States Census sends out responses to each household, and while legally obligated, there is a great deal of non-response. The number of mail responses by CBSA for 1990 was obtained from the United States Census website: <http://www.census.gov/dmd/www/mailresp.html>. These data were compared to the number of households in each CBSA in 1990.

### 2.5. Exponent fits

The data were all compared to the US Census CBSA data for the appropriate year. Generalized linear models [16] were implemented for the logarithm of the social variable against the logarithm of the population size. Models were fit using

**Table 1**  
Scaling of prosocial behaviors. The exponents for the power law fits are shown.

	Behavior	Exponent ( $\alpha$ )	$2 \times \text{SE}$	$R^2$
Sublinear	Census mail rates	0.988	0.010	0.977
Linear	Living organ donation	0.988	0.015	0.922
	Voting	1.008	0.011	0.974
Superlinear	Deceased organ donation	1.030	0.020	0.884
	Political contributions (number)	1.281	0.037	0.837
	Political contributions (dollar amount)	1.352	0.039	0.836



**Fig. 1.** Scaling of prosocial behaviors against metropolitan population or households. A. Census mail responses. B. Living organ donations. C. Voting. D. Deceased organ donations. E. Number of political contributions. F. Amount of political contributions.

both a Gaussian and a negative binomial for the error distributions and link functions. For both models, the coefficient corresponds to the exponent in a superlinear scaling model. Each was tested to see if they differed from an exponent of 1 by more than two standard errors, in order to determine if the fits were sublinear or superlinear. The model chosen was based on the median CBSA value for each variable: if the inverse square of the Gaussian parameter was found to be larger than the median value, the negative binomial model was chosen; otherwise, the Gaussian model was used. The squared value of the correlation coefficients ( $R^2$  values) were reported for the data and model, when scaled logarithmically.

### 3. Results

#### 3.1. Empirical results

We examined five prosocial behaviors—organ donation by deceased individuals, organ donation by living individuals, voting, political contributions, and US Census mail responses. Looking at how their occurrence scaled with the population size of the metropolitan area, the behaviors were classified into one of three categories: sublinear, linear, and superlinear.

Table 1 shows this division, with the behaviors and associated exponents listed in order from sublinear to linear to superlinear scaling exponents. A sample fit is shown in Fig. 1.

In addition, we checked to see if these variables were correlated with population density (when divided by population); these were found to be not significant.

While prosocial behaviors can have higher scaling exponents than one, they do not obey a clear pattern.

#### 4. Discussion

Prosocial behavior, while inherently social, like many productive and creative behaviors, appears to be in a different class. These behaviors do not scale similarly and are different from productive behaviors that have previously been examined, such as patents and economic growth across cities. Furthermore, our quantitative results confirm the somewhat contradictory initial findings related to lost letters and helping strangers: prosocial behavior is not a single category when it comes to understanding urban scaling with respect to population. Furthermore, it does not even appear that seemingly antisocial behavior follows a single category of scaling; for example unlike crime more generally, which scales superlinearly, as noted above, recent work suggests that the number of prostitutes (a particular kind of illegal activity) scales sublinearly [17]. Of course, there is little variation in most of the scaling exponents, and perhaps less than estimated due to measurement error, so further examination of other examples of prosocial behavior is warranted.

Bettencourt et al. argue that all growth, including urban expansion, is constrained by the availability of resources, which are necessary for both maintenance of structure as well as growth [3]. If the resources necessary for adding new cells to an organism, or a new individual to an urban population, scale sublinearly, then calculations can show that the growth will follow a sigmoidal curve, until a 'carrying capacity' is reached. This growth is characteristic of living organisms, which eventually reach a maximal size as adults, since they are limited by such factors as blood supply.

For cities, however, where such growth is often driven by innovation and the creation of wealth, then the growth can be superlinear. Rather than cities ceasing growth and reaching a similar maximal size, they continue to grow. However, this growth will in fact occur faster than exponentially, leaving it unsustainable. Bettencourt et al. argue that continued urban growth must therefore occur alongside continued innovation, allowing cities to overcome this overwhelming growth, and 'reset' the terms of the growth equations.

Is a similar argument true for prosocial behavior? In order for a group of individuals to endure, there needs to be some amount of prosocial behavior that justifies staying together rather than disintegrating [5], and it is reasonable to assume that the amount of prosocial behavior in a group must increase to integrate new individuals into a population. However, it is unclear under what conditions an additional individual can be added to a population and how energy-related the considerations for prosocial behavior are. For example, if it is the case that the amount of effort to add another person to a population requires less prosocial effort (by the person or by the collective) than the previous person, then it is unsurprising to find that prosocial behavior can scale sublinearly.

In addition, while Arbesman et al. [4] used a model based on social hierarchies and collaboration to provide a mathematical foundation for the superlinear scaling of productivity and innovation, that model need not be appropriate here. Prosocial behavior, while fundamentally related to human interaction, is often based on more evanescent contacts. Rather than assuming something about the structure of urban social networks and collaborations, a simpler model based on more fluid interactions might be more reasonable.

For example, whether a particular class of prosocial behavior scales linearly, superlinearly, or sublinearly might be dependent on two factors: the locality of one's interactions, and feedback of interaction. For locality, this refers to whether or not you are limited to the individuals around you, or can interact with anyone in the city. Feedback is the nature of how each individual's interactions affect others. Negative feedback means that my own action makes yours less likely, and positive feedback is the opposite. The combination of these factors, which at present are difficult to quantify, might dictate how each prosocial behavior scales.

The potential for understanding the spectrum of scaling of prosocial behaviors points to the wide variety of aspects of seemingly related behaviors. Their implications for urban growth are intriguing and merit further examination.

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