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Is there more traffic congestion in larger cities? -Scaling analysis of the 101 largest U.S. urban centers-

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ABSTRACT

Over the past three decades, urban congestion has become more costly in terms of time, money, and fuel. For the top 101 largest US urban centers, congestion generated 4.8 billion hours of travel delays in 2011, up from 1.1 billion hours in 1982. Congestion also required 8.419 million cubic meters of excess fuel consumption in 2011, up from 1.73 million cubic meters in 1982. Finally, the excess CO_2 emitted from congestion amounted to 19.524 billion kilograms in 2011, up from 3.94 billion kilograms in 1982. We examined the scaling relationships between the population sizes of urban centers and traffic congestion for four subgroups of urban centers with varying population sizes. We found that scaling relationships were superlinear for most subgroups. However, for the subgroup comprising mega cities with populations of over 3 million people, the relationship was linear.

The varying scaling relationships we found for cities with different population sizes may resolve the contradictory scaling results reported in the extant literature. Several other implications from our findings are also discussed.

1. Introduction

According to the Smart Mobility Report (2015), the average American spends about 34 h every year in traffic. The economic opportunity cost is staggering at about $124 billion every year. If nothing changes, this cost could increase to $186 billion by 2030. The cost of road congestion in Europe is estimated to be over € 110 billion a year or equivalent to 1% of the GDP, although this varies among countries from 1.6% for the United Kingdom and Poland to 0.5% for Slovakia and Spain (Christidis and Ibanez Rivas, 2012). The average speed of vehicles in Bangkok in Asia was 15 km/h, while that in Manila, Jakarta, and Singapore was 18 km/h, 19 km/h, and 20 km/h respectively. During peak hours, the speed on roads in Delhi and Mumbai drops to 10–20 km/h (Absar and Ahmed, 2013).

Over the past three decades, congestion has become more costly in the US in terms of time, money, and fuel, according to the Urban Mobility Report (UMR) published by the Texas A&M Transportation Institute (TTI). The UMR (2012) includes 30 years of data from 1982 to 2011 on 101 of the largest urban centers in the US. According to the Performance Measure Summary or 101 Area Sum from the 2012 UMR, congestion generated 4.773 billion hours of total delays in 2011 for these 101 cities, up from 1.05 billion hours in 1982. Furthermore, congestion required 8.419 million cubic meters of excess fuel in 2011, up from 1.73 million cubic meters in 1982. Finally, the excess CO_2 emitted from congestion amounted to 19.524 billion kilograms in 2011, up from 3.94 billion kilograms in 1982. These large 101 urban centers comprise populations of 173.5 million people, of which 84.8 million were commuters in 2011. According to Puentes and Tomer (2008), the top 100 US metropolitan areas accounted for 64.1% of the total vehicle miles travelled in 2006, while the top 10 metropolitan areas accounted for 23.5%.

Among numerous studies examining the relationship between cities and automobile dependence and fuel usage, the best known (Newman and Kenworthy, 1989; Kenworthy and Laube, 1999) discovered a negative correlation between cities with a high population density and lower fuel usage. Essentially, the high population density in cities may discourage car ownership in favor of using public transit systems. High-density cities may also require shorter driving distances and encourage bicycling and walking. When this finding is examined within the framework of the scaling relationship between the population size of cities and total fuel consumption, the result indicates a sublinear scaling relationship. Thus, doubling the population size of a city will generate a less than proportionate increase in total fuel consumption. For example, if the scaling coefficient for population is 0.5, doubling the population size will only increase total fuel consumption by 41.4% ($2^{0.5} = 1.414$).

However, a recent paper by Loaf and Barthelemy (2014) empirically established a superlinear scaling relationship between cities' population sizes and the two measures of roadway congestion in both the US and OECD countries. For example, Loaf and Barthelemy derived the

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population coefficient of 1.27 for the variation of total delay hours due to congestion as well as the population coefficient of 1.262 for excess CO_2 emissions due to congestion. In other words, if a city's population size increases by 100%, the total hours delayed and excess CO_2 emissions from congestion may increase by 141% ($2^{1.27} = 2.41$). These coefficients are derived from the 2012 UMR database for 97 of the largest urban centers in the US. In other words, they established a clear-cut superlinear relationship between the population sizes of urban centers and the two measures of urban roadway congestion. The report concluded that large cities relying on the use of automobiles as the dominant transportation mode would eventually face the question of sustainability in the future.

To our knowledge, the paper by Loaf and Barthelemy represents the first published work to systematically establish a superlinear scaling relationship between population size and congestion. Proven valid, their findings will have a significant impact on both the theory and practice of coping with traffic congestion in cities. Therefore, our study examines the proposed scaling relationship between the population size of cities and traffic congestion in detail.

Specifically, we examine the following three questions in our paper:

1. Do larger urban centers experience disproportionately greater traffic congestion, thus creating longer delay hours, larger excess CO_2 emissions, and a larger excess of fuel consumption?
2. If so, do these scale relationships vary between subgroups comprised of urban centers with different population sizes?
3. What other control variables besides population size influence these relations?

For our analysis, we used the total hours of delays, excess fuel consumption, and excess CO_2 emission due to congestion for 101 of the largest urban centers in the US. This information was available from the TTI's Urban Mobility Information website. The data spans a 30-year period from 1982 to 2011. We also used the population size, number of commuters, the freeway's lane-miles, and the lane-miles of arterial streets, information all available from the same source.

Following the introduction, this paper is organized into four additional sections. The second section presents a brief literature survey on the scaling relationship between the population size and/or population density of cities and urban traffic congestion measures. In the third section, we explain our method of analysis and data. The fourth section presents the results of our analysis. Finally, the fifth section presents our conclusion and the limitations of this study.

2. Literature review

Many studies examined the relationship between cities and automobile dependence and fuel usage. The first pioneering paper by Newman and Kenworthy in 1989 established a negative correlation between cities with a high population density and lower annual fuel usage per capita. Their research analyzed 32 very large cities on four continents. Specifically, variables such as the fuel price and vehicle efficiency explained 40% of energy consumption, while the remaining 60% was attributed to the level of urban density. As a follow-up study, Kenworthy and Laube (1999) used a larger set of cities, finding that the correlations of urban density for car ownership, car use, and transit use were stronger than the corresponding correlations for gross regional product and car user costs. These two papers provided strong arguments for implementing the concept of the compact city to reduce vehicle dependency in cities. Furthermore, they generated numerous follow-up articles either supporting or contesting their findings (Mindali et al., 2004; Bento et al., 2005; Brownstone and Golob, 2009; Small and Van Dender, 2007; Karathodorou et al., 2010; Coevering and Schwanen, 2006; Su, 2011). For example, Mindali et al. (2004) found no correlation between urban density and fuel consumption. Instead, they found negative correlations for the inner area and central business district with employment density and the use of public transportation. However, both studies by Karathodorou et al. (2010) and Su (2011) found statistically significant negative population density coefficients of −0.229 and −0.064 for fuel consumption, supporting the earlier findings by Newman and Kenworthy.

In addition, Su (2011) found that the level of congestion affected the gasoline consumption of households in selected urban areas in the US. This finding suggests that a 1% increase in the number of hours of delay per peak hour per year increases household fuel consumption by 0.8 gallons.

A vast amount of literature describes the causes and effects of urban traffic congestion and mitigation strategies (Gordon et al., 1991; Burton, 2000; Levine and Garb, 2002; Taylor, 2002, 2004; Downs, 2004; Stopher, 2004; Loaf and Barthelemy, 2014; Mishalani et al., 2014). For example, Taylor (2002) states that the most densely populated cities tend to be the most congested, because vehicle travel decreases more slowly than when population density increases. This claim was supported by an empirical study (Gordon et al., 1991) suggesting that the time for commuting by automobile is 25–30% higher for dense cities such as New York and Chicago than dispersed cities like Dallas and Phoenix. They suggested that dispersed cities may offer more opportunities for faster commutes, for example, through changes in residence or job, the relocation of firms, or the choice of uncongested routes.

According to Downs (2004), the most obvious reason for congestion is population growth. Since the growth of the population is faster in urban areas, he predicted that traffic congestion in nearly all large metropolitan regions worldwide would worsen. Stopher (2004) concludes similarly, stating that "increasing wealth, increasing expectations of mobility, willingness to pay for travel, and the increasing population" will generate increasing congestion levels. Extending this modern concept of congestion, it is expected that economically vibrant cities could have the worst congestion problems.

A more comprehensive study examining the relationship between the population size of cities and traffic congestion was recently published (Loaf and Barthelemy, 2014). These authors explicitly incorporated the trade-off between income from a given job versus commuting time to the job's location in developing their theory of polycentric cities. They developed analytical models to represent traffic congestion and several other related measures. For polycentric cities, their models enabled the prediction of a numerical scaling measure. For example, their model predicted the population coefficient of total delay due to congestion as ranging from 1.32 to 1.22. They then empirically derived the population coefficient of 1.27 ± 0.067 from the 2010 data for 97 urbanized areas in the US. Their analytical model predicted the population coefficient of excess CO_2 emission from congestion as ranging from 1.32 to 1.22. Furthermore, they estimated 1.262 ± 0.089 to be the empirically derived population coefficient of excess CO_2 emission due to congestion from the 101 metropolitan areas in 2010.

As such, they established a clear-cut superlinear relationship between the population size of these large urban centers in the US and the two measures of traffic congestion. They suggested that large cities relying on the use of automobiles as the dominant transportation mode would eventually face the question of sustainability in the future.

In conclusion, the negative correlations established by Newman and Kenworthy (1989) and many others in the literature indicate that the scaling relationship between the population size of cities and total fuel consumption may follow a sublinear relationship. On the other hand, Loaf and Barthelemy (2014) established a superlinear scaling relationship between the population size of cities and the two measures of roadway congestion for total delay hours and excess CO_2 emissions from congestion. As such, a useful contribution is to develop a framework that accommodates both these findings.

3. Methods and data

The group of 101 urban centers was divided into four subgroups comprising cities with varying population sizes. The first subgroup contained cities with a population of more than 3 million people, followed by