Cities: Large is Smart

BY JENNA BECK

In an attempt to discover whether cities consume energy in the same way as biological organisms, SFI External Professor Luis Bettencourt, SFI President Geoffrey West, and their colleagues from Arizona State University and the Dresden University of Technology found that the size of a metropolis not only affects energy consumption, but also the pace at which people work, earn, walk, spend, and steal. Their study, published in the April 24th issue of the *Proceedings of the National Academy of Sciences USA,* lays out scaling laws that appear to connect cities of different sizes and in different nations. The most surprising of these laws suggests that a city may have a social metabolism that, as the city grows, increases faster than the population itself.

"A city's not just a place, just a culture, what people eat, what language they speak," says Luis Bettencourt. "It's a space of interaction. When you put more and more people together in a city, some things increase in a very predictable and interesting way." Using data from international census and statistics bureaus, the researchers compared infrastructure, energy consumption, and a handful of social phenomena for cities large, small, and in between. They found that as a city's size increases, the infrastructure networks realize economies of scale, while the social phenomena grow faster than the population. In other words, the surface areas of streets and the lengths of electrical cables lag behind a city's

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This satellite image of North America at night illustrates the density of populations in the coastal regions as well as major inland cities, with large stretches of plains, deserts, and mountains remaining dark. Dawn is breaking over the eastern coast of the U.S.A.

Big cities will continue to grow, researchers believe, and understanding such places may help protect them from economic crisis. Here Shanghai's notable sector, The Bund, along the Huangpu River, buzzes with activity.

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population growth, whereas income, crime rates, disease transmission, and certain measures of innovation outpace it.

Understanding these phenomena is a timely endeavor. For the first time in history there are roughly the same number of people living in cities as in rural areas, and the United Nations projects that cities will absorb the bulk of the population growth in the next 30 years. Big cities will grow bigger, as will the number of small cities. Between now and 2015, half of the urban growth is expected to come from an increase in the number of small cities with populations of fewer than 500,000 people.

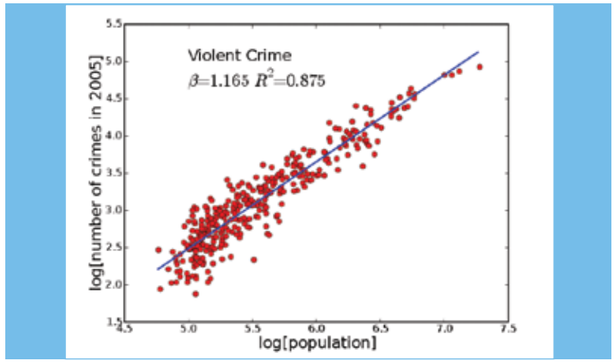
From an economic perspective, a growing city is usually seen as a healthy one. After all, the world's largest urban centers currently drive the world's largest economies. But while growth can benefit a city's economy, a city's future is by no means ensured. According to the UNFPA State of World Population 2007 Report, there are actually more people moving out of Buenos Aires, Calcutta, Mexico City, São Paulo, and Seoul than are moving in. Furthermore, the economic advantages do not extend to all urbanites. The report projects that "poor people will make up a large part of future urban growth," since much of the growth is projected to occur in the developing world, where cities do not generate enough jobs to accommodate their populations. In light of the global urban upswell, questions of how a city grows, how it is sustained and affects the environment, and how, as an environment, it affects its citizens become increasingly important. The scaling laws presented in the researchers' paper lay down a quantitative base for exploring such questions.

After analyzing datasets from American, Chinese, and European government bureaus, the researchers found three different scaling laws for three categories of data: individual human needs, material infrastructure, and data related to social currency.

Individual human needs included housing, employment, household electrical consumption, and household water consumption. These scaled linearly for cities of different sizes, which suggests that a person's basic requirements for work, a home, and utilities remain the same whether he lives in New York or Nantucket.

Infrastructure was measured by road surface area, length of electrical cables, gasoline sales, and number of gas stations. The infrastructure scaled sub-linearly as city size increased, which means it didn't grow as quickly as the population. When more people use fewer roads, gas stations, etc., a city realizes an economy of scale. Large cities, up to a point, are a more economic way of distributing resources than small cities and rural communities. This mirrors a relationship seen in biological organisms, where large animals economize on blood vessels by pumping more blood through proportionally fewer veins and capillaries. Fewer vessels support more mass, but the large animal's metabolism slackens because the blood is delivered more slowly. When a city grows, the highways deliver more people to and from their destinations, but traffic slows as the roads become congested.

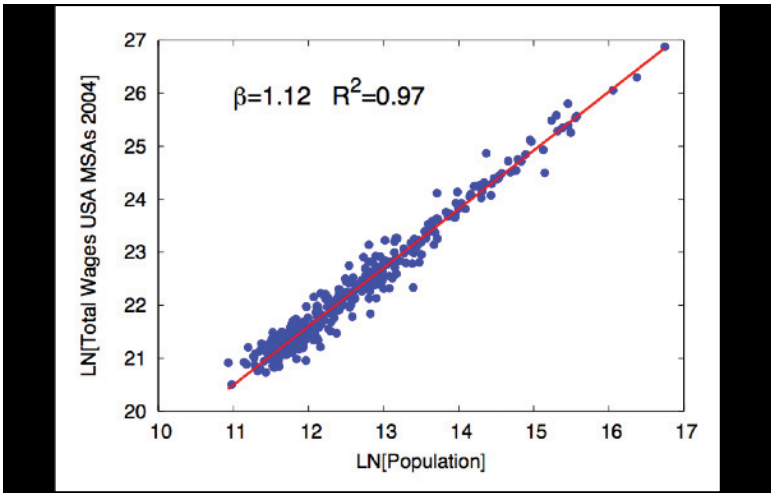
To the researchers' surprise, the biological parallel failed for the third category of data: social currency. Unlike an animal's metabolism, which slows with increasing size, as city size increased, the social metabolism sped up. "Superlinear" is the term the researchers use to describe this metabolic growth rate, which, when graphed, maps a steep upward curve rather than a straight line. "It was quite a surprise when we discovered this whole superlinear scaling. Like many things, once you see it and think about it, it seems obvious," says Geoffrey West. "But it wasn't obvious at first." The social currency category included a range of seemingly unrelated measurements. Some of these—number of new patents, inventors, employment in research and development,



Violent crime per capita increases with city size (USA, 2005) as a scaling law.

and creative employment—were loose measures of innovation. Others were measures of consumption: total wages, total bank deposits, gross domestic product, and total electrical consumption. The researchers also took account of such things as the number of new AIDS cases and serious crimes.

As diverse as the social data were, they all scaled superlinearly with roughly the same exponents. This led the researchers to conclude that an underlying social metabolism was driving their growth. "We went into the study trying to



Total wages per metropolitan area indicate increasing per capita returns versus population size.

test the economies of scale theory, first for energy consumption," Bettencourt says. "It's only because we kept finding superlinear scaling for energy consumption—and then in everything economic—that it became so obvious that everything social showed increasing returns to population. All these quantities are rates, meaning that their increase per capita with the size of the city is an expression of acceleration of social life."

As a city grows, its social metabolism speeds up. Individual productivity rises (15% per person when the city doubles) as people get busier. Average walking speeds increase. Businesses, public spaces, nightclubs, and public squares consume more electricity. The city draws in more inventors, artists, researchers, and financiers. Wealth increases, as does the cost of housing.

The superlinear growth rates also suggest that a city can grow indefinitely. When the researchers plugged the scaling exponents into an urban growth equation, they found that cities driven by economies of scale were destined to plateau, whereas those driven by innovation or wealth creation had the potential for unbounded growth. "Should a city have a finite size or should it grow forever? How should it grow? You would argue about it forever if you hadn't measured," Bettencourt says.

Sustaining that growth is the city's chief challenge. To grow indefinitely, a city has to periodically reset its growth rate. Such "resetting" can come from innovations that revitalize the economy, or from outside factors, such as shifts in immigration. The pattern that an ever-growing city falls into is one of successive growth cycles—each one shorter than the last as the size of the city increases. "You're on this treadmill and you've got to go on making these changes, these innovative changes, faster and faster because if you don't you'll stagnate and collapse," West says. "It's probably hard to have control over these things because a city is embedded in something bigger. My interpretation is that where that cycle ends up might depend upon whether you have a city with a good administration in place, but the general trend and the coarse-grained scale of it is probably determined for you."

If a growing city does not reset, the growth will collapse when the city exhausts its resources, or when its infrastructure and economy cannot support the population. Bettencourt cautions that a city can also collapse when the dark side of social metabolism accelerates more quickly than the rest: "My intuition, which is something I'd love to measure, is that the bad things can respond more quickly: it's easy to increase the cost of housing. It's easy to increase crime. It's easy to create congestion—it just happens."

The researchers are now looking into Bettencourt's intuition about the balance between negative and positive social behaviors. They are also working to determine whether population and economic diversity increases with city size and, if so, whether those factors can help protect a city from economic crisis. "What's difficult," adds Bettencourt, "is to create institutions that promote very advanced learning and creativity." Knowing more about cities just might make the task easier. ◀

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