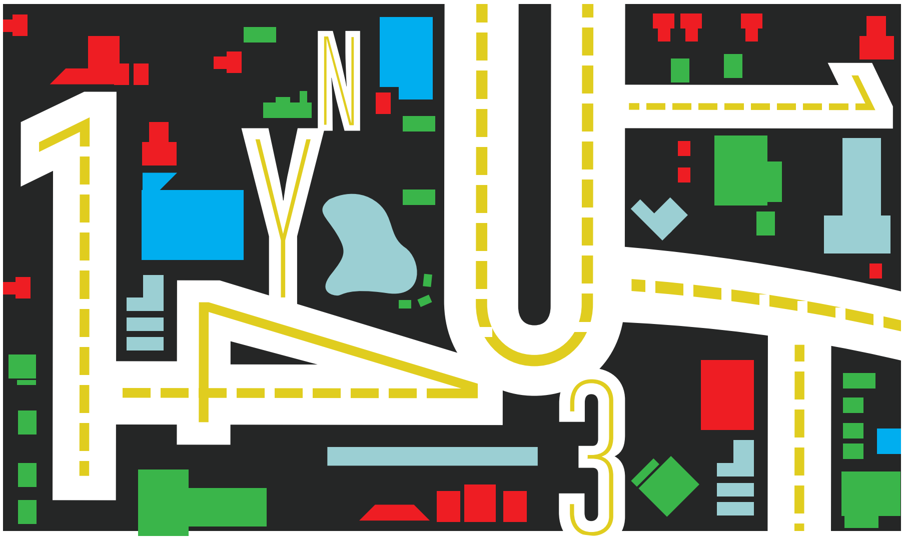

OLIVER MUNDAY

A unified theory of urban living

It is time for a science of how city growth affects society and environment, say **Luis Bettencourt** and **Geoffrey West**.

At the start of the twenty-first century, cities emerged as the source of the greatest challenges that the planet has faced since humans became social. Although they have proven to be humanity's engines of creativity, wealth creation and economic growth, cities have also been the source of much pollution and disease. Rapid urbanization and accelerating socio-economic development have generated global problems from climate change and its environmental impacts to incipient crises in food, energy and water availability, public health, financial markets and the global economy[1,2].

Urbanization is a relatively new global issue. As recently as 1950, only 30% of the world's population was urbanized. Today, more than half live in urban centres. The developed world is now about 80% urban and this is expected to be true for the entire planet by around 2050, with some 2 billion people moving to cities, especially in China, India, southeast Asia and Africa[2].

Cities are complex systems whose infrastructural, economic and social components are strongly interrelated and therefore difficult to understand in isolation[3]. The many problems associated with urban growth and global sustainability, however, are typically treated as independent issues. This frequently results in ineffective policy and often leads to unfortunate and sometimes disastrous unintended consequences. Policies meant to control population movements and the spread of slums in megacities, or to reverse urban decay, have largely proven ineffective or counterproductive, despite huge expenditure.

In New York City in the 1970s, for example, a strategy of 'planned shrinkage' intentionally removed essential services from some urban areas — notably the Bronx — to prompt people to move away and allow for redevelopment. Instead, this strategy led to increases in crime and general socio-economic degradation. In North America in the 1950s to 1970s (and earlier in Europe), policies of urban renewal intended to reduce high urban densities, by razing poorer old neighbourhoods and creating infrastructure, actually ended up encouraging urban sprawl[3]. Similar debates continue to play out in rapidly developing cities around the world today, from Beijing to Rio de Janeiro in Brazil, often leading to similar mistakes.

But cities supply solutions as well as problems, as they are the world's centres of creativity, power and wealth. So the need is urgent for an integrated, quantitative, predictive, science-based understanding of the dynamics, growth and organization of cities. To combat the multiple threats facing humanity, a 'grand unified theory of sustainability' with cities and urbanization at its core must be developed. Such an ambitious programme requires major international commitment and dedicated transdisciplinary collaboration across science, economics and technology, including business leaders and practitioners, such as planners and designers. Developing a predictive framework applicable to cities around the world is a daunting task, given their extraordinary complexity and diversity. However, we are strongly encouraged that this might be possible.

UNIVERSAL FEATURES

Cities manifest remarkably universal, quantifiable features. This is shown by new analyses of large urban data sets, spanning several decades and hundreds of urban centres in regions and countries around the world from the United States and Europe to China and Brazil[4,5]. Surprisingly, size is the major determinant of most characteristics of a city; history, geography and design have secondary roles[4,6].

Three main characteristics vary systematically with population. One, the space required per capita shrinks, thanks to denser settlement and a more intense use of infrastructure. Two, the pace of all socio-economic activity accelerates, leading to higher productivity. And three, economic and social activities diversify and become more interdependent, resulting in new forms of economic specialization and cultural expression.

We have recently shown that these general trends can be expressed as simple mathematical 'laws'. For example, doubling the population of any city requires only about an 85% increase in infrastructure, whether that be total road surface, length of electrical cables, water pipes or number of petrol stations[4]. This systematic 15% savings happens because, in general, creating and operating the same infrastructure at higher densities is more efficient, more economically viable, and often leads to higher-quality services and solutions that are impossible in smaller places. Interestingly, there are similar savings in carbon footprints[7,8] — most large, developed cities are 'greener' than their national average in terms of per capita carbon emissions. It is as yet unclear whether this is also true for cities undergoing extremely rapid development, as in China or India, where data are poor or lacking.

Similar economies of scale are found in organisms and communities like anthills and beehives, where the savings are closer to 20%[9]. Such regularities originate in the mathematical properties of the multiple

SCIENCE AND THE CITY
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networks that sustain life, from the cardiovascular to the intracellular[9]. This suggests that similar network dynamics underlie economies of scale in cities.

Cities, however, are much more than giant organisms or anthills: they rely on long-range, complex exchanges of people, goods and knowledge. They are invariably magnets for creative and innovative individuals, and stimulants for economic growth, wealth production and new ideas — none of which have analogues in biology.

The bigger the city, the more the average citizen owns, produces and consumes, whether goods, resources or ideas[4]. On average, as city size increases, per capita socio-economic quantities such as wages, GDP, number of patents produced and number of educational and research institutions all increase by approximately 15% more than the expected linear growth[4]. There is, however, a dark side: negative metrics including crime, traffic congestion and incidence of certain diseases all increase following the same 15% rule[4]. The good, the bad and the ugly come as an integrated, predictable, package.

Our work shows that, despite appearances, cities are approximately scaled versions of one another (see graph): New York and Tokyo are, to a surprising and predictable degree, nonlinearly scaled-up versions of San Francisco in California or Nagoya in Japan. These extraordinary regularities open a window on underlying mechanism, dynamics and structure common to all cities.

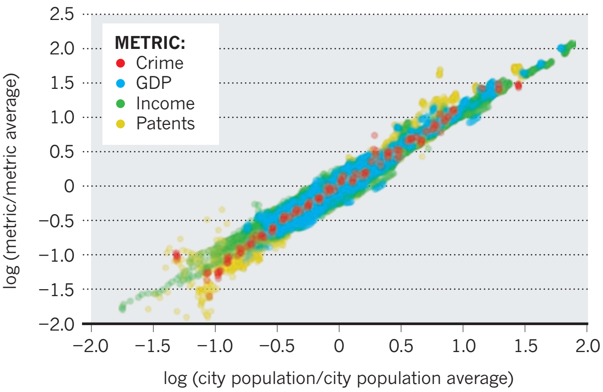
Deviations from these scaling laws, illustrated by the spread of data in the figure, measure how each city over- or under-performs relative to expectations for its size[6]. Relatively large deviations (as much as 30%) are seen for quantities with small numbers, such as patents and murders, whereas much smaller deviations (with variances less than 10%) are seen for economic properties. We also find that quantities such as GDP are more variable for urban centres in developing countries, such as China and Brazil, than for older cities in developed areas such as North America or Japan. It is unclear whether this is a fundamental property of developing nations or an artefact of data collection.

In biology, the network principles underlying economies of scale have two profound consequences. They constrain both the pace of life (big mammals live longer, evolve slower, and have slower heart rates, all to the same degree[9]), and the limits of growth (animals generally reach a stable size at maturity[10]). In contrast, cities are driven by social interactions whose feedback mechanisms lead to the opposite behaviour. The pace of urban life systematically increases with each expansion of population size: diseases spread faster, businesses are born and die more often and people even walk faster in larger cities, all by approximately the same 15% rule[4]. Moreover, this social network dynamic allows the growth of cities to be unbounded: continuous adaptation, not equilibrium, is the rule.

Open-ended growth is the primary assumption upon which modern cities and economies are based. Sustaining that growth with limited resources requires that major innovations — such as those historically associated with iron, coal and digital technology — be made at a continuously accelerating rate. The time between the 'Computer Age' and the 'Information and Digital Age' was some 20 years, compared to thousands of years between the Stone, Bronze and Iron Ages. Making major technological paradigm shifts systematically faster is clearly not sustainable, potentially leading to collapse of the entire urbanized socio-economic fabric. Avoiding this requires understanding whether we can continue to innovate and create wealth without continuous growth and its compounded negative social and environmental impacts.

PREDICTABLE CITIES

Data from 360 US metropolitan areas show that metrics such as wages and crime scale in the same way with population size.



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ACTING ON EVIDENCE

The job of policy-makers is to enhance the performance of their city relative to baselines for their size defined by scaling laws. Although a scientific understanding of how cities work may not be prescriptive for policy-makers, recent work should help them to encourage positive urban development.

Our research shows that cities are remarkably robust: success, once achieved, is sustained for several decades or longer[6], thereby setting a city on a long run of creativity and prosperity. A great example of success is metropolitan San Jose, home to the Silicon Valley, which has been consistently over-performing relative to expectations for its size for at least 50 years, well before the advent of modern hi-tech industry. Unfortunately, the reverse is also true: it is very hard to turn around urban decay swiftly. Ineffective policy and unrealistic short-term expectations can condemn a city to decades of under-performance: witness former industrial cities such as Buffalo, New York.

Today's rapid development and urbanization provides an opportunity to collect detailed data that will illuminate the links between economic development and its undesirable consequences. Policy initiatives in developed and developing cities should be viewed as experiments that, if carefully designed and measured, can help support the creation of an integrated, predictive theory and a new science of performance-based planning. Examples of this approach are increasingly common, both among poster children such as Barcelona in Spain or Curitiba in Brazil, and as part of new initiatives in New York or London. Ideally, by coupling general goals (such as lower carbon emissions) to actionable policies and measurable indicators of social satisfaction, successes and failures can be assessed and corrected for, guiding development of theory and creating better solutions.

Cities are the crucible of human civilization, the drivers towards potential disaster, and the source of the solution to humanity's problems. It is therefore crucial that we understand their dynamics, growth and evolution in a scientifically predictable, quantitative way. The difference between 'policy as usual' and policy led by a new quantitative understanding of cities may well be the choice between creating a "planet of slums" or finally achieving a sustainable, creative, prosperous, urbanized world expressing the best of the human spirit. ■

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