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A systematic approach toward an urban science

Recent scholarship has employed the rigorous tools and computational power of the physical sciences to provide quantitative measures of the problems of cities. This ambition has captured the notice of public policy makers eager for solutions to what are often seen as intractable problems. In the United States, a recently announced initiative backed by the White House will see 21 partnerships formed between cities and universities to study "smart cities"[1]. Similar initiatives are backed in Europe and Asia[2]. As funding for these programs increases and as policy makers increasingly rely on their results, the practitioners of "urban science" will need to defend their claims to expertise. In this paper, we address the question of whether there can be an "urban science," with the precision and deterministic certainty that is implied by "science. We first look at the nature of scientific inquiry and how science has come to be defined. We then review how urban theorists have applied scientific principles in previous studies and identify how urban science fits in the model of science and where it has gaps. We conclude by positing what the field can do to firmly establish itself as a science.

Whether "urban science" can be a science at all is a question of epistemology. Although other methods were described earlier, the programs of René Descartes and Francis Bacon began to establish a systematic approach to developing scientific knowledge. Descartes' solipsism forms the foundation for his school of rationalist thought, which prioritizes deductive process from fundamental ideas that scientists can convince themselves are absolutely true[3]. Bacon's approach prioritizes inductive reasoning from observations of and experiments with the physical world[4]. Urban science's emphasis on data collection fits Bacon's view, but it cannot ignore the Cartesian mandate to identify fundamental principles. Both models have influenced the philosophy of science and form what we now call the scientific method.

Karl Popper made further advances to the scientific method by rejecting induction and advocating critical rationalism, whereby scientific theories can never be proven by observation, but can be invalidated by falsification[5]. The concept of falsification overcomes a limit of induction: while any number of theories can be created to explain an inductive conclusion, only falsifiable ones can ever be tested and examined. This condition precludes supernatural causes or unfounded speculation from argument. For this reason, falsification is frequently used as a criteria separating science from pseudoscience[6].

Falsification has not been accepted by all philosophers, though. Paul Feyerabend's radical view of epistemological anarchism advocates that *any* rationalist methodology (including Popper's critical rationalism) necessarily restricts progress and should be rejected. He also argues that science has historically advanced not only through empirical evidence but also through social means that do not conform to conventional scientific methods[7]. Feyerabend's positions have generally held less sway in science than in critical theory (perhaps because of his explicit rejection of falsifiability), so for the purposes of determining criteria for urban science that both science and larger society can identify, we shall adopt the Popperian view.

It is instructive to review how other fields have advanced their aspirations to be treated as bona fide sciences, such as computer science. A commonly invoked criterion of a science is that it should deal with strictly natural phenomena. Since computers are creations of people, skeptics of a computer "science" argue that any insights of the field only apply to artificial phenomena associated with the technologies used in the construction of the machine; that is, it can be engineering, but not science[8]. While this argument has frustrated computational theorists whose intuition was that their field was built upon fundamental natural principles, it was breakthroughs in molecular biology and quantum physics that eventually came to the defense of computer science: the encoding mechanisms of DNA and quantum mechanical theories of information have been proffered as natural computing processes. If one accepts these arguments, then computation becomes a fundamental process of nature, and computers are just a method of exploring it[8]. Although it is still a subject of epistemological debate among some philosophers, computer science is now generally regarded (at least by scientists in other fields) as a science[8].

Cosmology's status as a science has also been debated by physicists and philosophers. Here, the objections have regarded the violation of the principle of falsifiability. In 1948, Fred Hoyle, Thomas Gold and Hermann Bondi proposed a "steady state" theory of the Universe, in opposition to the competing "big bang" theory. Steady state theory required the *a priori* assumption called the "perfect cosmological principle," that the observable universe is spatially and temporally homogeneous. Popper himself attacked a less restrictive cosmological principle as unfalsifiable, and therefore unscientific. In 1964, the discovery of the cosmic microwave background showed that the assumption was not only testable, but was in fact incorrect, invalidating the model[9] and redeeming the principle of falsifiability. Current cosmological theories like multiverses face similar hurdles or testability and falsifiability, except now the assumptions are so esoteric that it seems unlikely that observation can ever provide insights[9]. This has led some to wonder whether falsifiability should lose its sacrosanct status: the tools to verify the proposals are not available and may be beyond humanity's ability to create them, so perhaps the definition of science should bend to permit these theories[10]. This echoes in part Paul Feyerabend's motivation for epistemological anarchism, that scientific progress is held back by rigid adherence to methodology.

These two examples hint at arguments that are likely to be raised against an urban science: that cities are anthropic systems, not natural phenomena; and that any theoretical explanation of cities must have methods of verification and falsification. We take each of these arguments in turn.

Studies associated with urban science frequently focus on technologies such as geographic information systems, sensors and data mining to gain perspectives on the built environment of cities. Studies that glean mechanistic explanations of urban dynamics in human-built cities from these analyses are more difficult to find. The works of Luis Bettencourt attempt to find common patterns in growth for cities using metrics such as wealth[11], patents[12] and crime[13]. These papers find compelling trends in growth, but offer less compelling explanations of mechanism. One analysis of criminal statistics in Latin America shows trends consistent with "Zipf's law," an empirical observation motivated by statistical linguistics but shown to hold for other sociological phenomena. Although descriptive, it is not explanatory: why should Zipf's law hold for Latin American crime? The argument fails to identify a natural cause for the observed phenomena.

Another study by Bettencourt *et al*[14] of "diverse properties" of cities identifies similar trends across a wider geographic set, including the United States, Europe and China. In this study, the scaling parameters are used to classify these properties into types associated with economies of scale, preservation, and increasing returns. To these types, the authors attach a tenuous association of cities to biological systems: "Are [biology analogies] just qualitative metaphors, or is there quantitative and predictive substance in the implication that social organizations are extensions of biology?" While conceptually appealing and descriptive, no evidence is provided to form any basis for this association as an explanation. If we do accept these models, what is the falsification mechanism?

Edward Glaeser[15] and Paul Krugman[16] have used mathematics to construct models of city economic dynamics. Both have created novel, simple models that produce spontaneous results consistent with known patterns of urban growth and agglomeration, but like the cosmological arguments, the models only fit the data; they do not provide a rational explanation for any underlying mechanism. The lack of clear mechanistic explanations of urban dynamics has been noted by Krugman: “The failure of existing models to explain a striking empirical regularity indicates that despite considerable recent progress in the modeling of urban systems, we are still missing something extremely important.”[17]

Where Krugman sees an occasion to be concerned, those aspiring to an urban science may be encouraged by the challenge of achieving the goal of Bettencourt and Geoffrey West for a “unified theory” of cities[18]. To do that will require an understanding of the fundamental processes that govern growth and decline of cities. Urban science has not yet arrived at this point, but the compelling evidence of empirical relationships seen in multiple disciplines suggests that “something extremely important” can be discovered by applying rigorous scientific methodology. The examples given above suggest that the theory of complex systems may be a fruitful avenue of inquiry, as Jane Jacobs may have suggested in her entreaty to study cities in the context of “organized complexity”[19]. Urban scientists will also need to understand the limits of their analyses and determine how theories can be falsified. Cities in the developing world may provide this opportunity: theories may apply equally in Omaha and Ouagadougou, but without performing the requisite analysis, we cannot know. If the analysis falsifies the theory upon the receipt of contradictory evidence, an opportunity exists to develop a better theory that gains insights from the anomalous data. This has been the hallmark of scientific advancement, and it is the path upon which urban science should set if it is to establish itself as a field of urban expertise and as a scientific endeavor.

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Notes

Nature of scientific inquiry
- Distinction from metaphysics or natural philosophy
- Descartes/Bacon vs Aristotelian syllogism (we are in Bacon's camp)
- Popper (addition of falsifiability)
- Empiricists

Other fields' aspirations to science
- Computer science (Peter Denning)
- Management (Frederick Taylor)
- Social science

Properties of 'urban science'
- Complex systems (Jane Jacobs)
- What are its principles? Denning; Bettencourt & West → "unified theory of urban living"
- Is it falsifiable vis a vis Popper?

How have urban thinkers applied science?
- Glaeser, Krugman (economics, mathematics)
- Bettencourt (appeal to biological comparison)
- CUSP initiatives (urban observatory, quanitified community) → is this science?

What's the difference between a science and other sciences applied to the domain? Does it become distinct?
- Machine learning paradigms, nature of computation
  - theoretical insight from application

Ability to make generalizations
- Do we have general, falsifiable theories to fit all observations?
- Do we have theories to explain "outliers"?
- Are they outliers? → Do outliers imply cities are statistical or does theory need to be expansive enough to explain them with a cohesive set of laws? If so, how to have a general theory that explains both Omaha and Ouagadougou?
- If not, then this is "just" engineering
- Engineering is still important and the tools developed may have general application (not just in an urban context)
- This makes it a viable and important field to study in a scientific context
- Still hope to develop science: theoretical insights come from sensory observation (Bacon, Popper)

What this does not cover:
- Outcomes necessarily become political because all hypotheses in the urban environment involve people (their homes, their capital)