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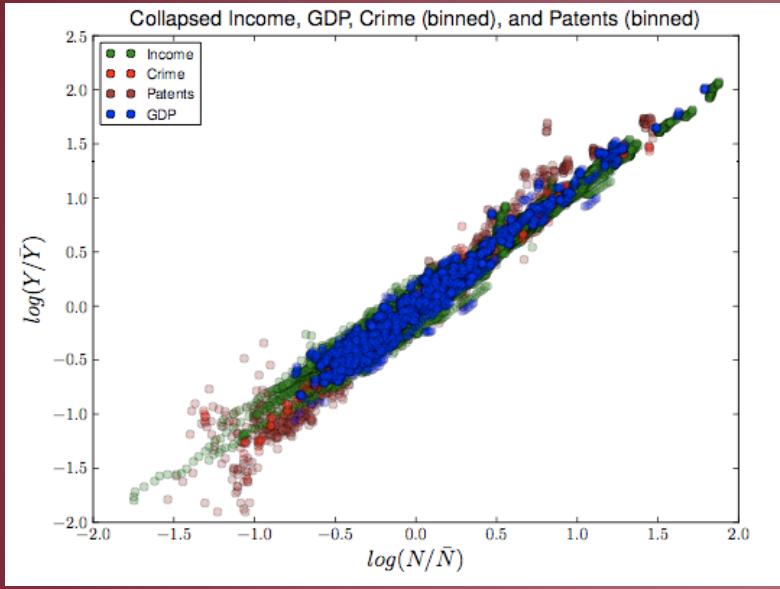
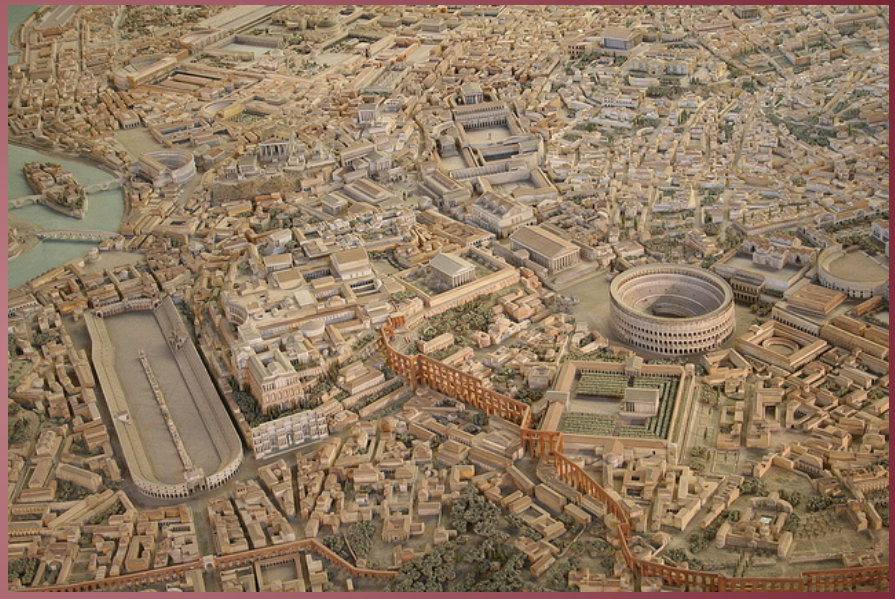
Urban Scaling and the Growth of Rome





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TRAC
Theoretical Roman Archaeology Conference

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Importance of Cities: Ancient and Modern

- Emergence, development, and sustainability
  - Interdisciplinary study
- A proxy for cultural, economic, and demographic growth and change
  - '*…towns as sites in which the history of larger systems—states, societies, modes of production, world economies—is partially, but crucially, worked out*' (Morley 2011)
- A world of cities:
    - **1800 – 4%** of US population urban; **2011 – 80%**
    - **2011 – 50%** of world population urban
    - Roman Italy in 28 BC: 15-35% of population urban?

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The Problem: A Theory of (ancient) Urbanization?

- *'…we need a theory of (ancient) urbanization and of the nature of the processes that supported the development of urban centres before we can attempt to delineate and quantify the parameters of this development, let alone begin to discuss the implications of this for the economy'* (Morley 2011)

- **How/what are we counting? Why significant?**
  - Quantitative and/or qualitative terminology?
  - The presence of cities is not enough - need to understand how cities function, what they provide, and how they grow
  - Sustainability?
  - Predictability?

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A Solution?
Urban Scaling and the Science of Cities

- Designed to obtain a grand unified theory of sustainability (and predictability) for urban development
  - **Luís Bettencourt** (theoretical physicist/complex systems)
  - **Geoffrey West** (physicist/biologist)

- **Questions:**
  - Are there quantifiable principles and/or power laws that cities follow (as in physics and biology)?
    - Do mathematical regularities that underlay biological systems also underlay social and urban systems?
  - Is there a (coarse grained) conceptual framework for predictability?

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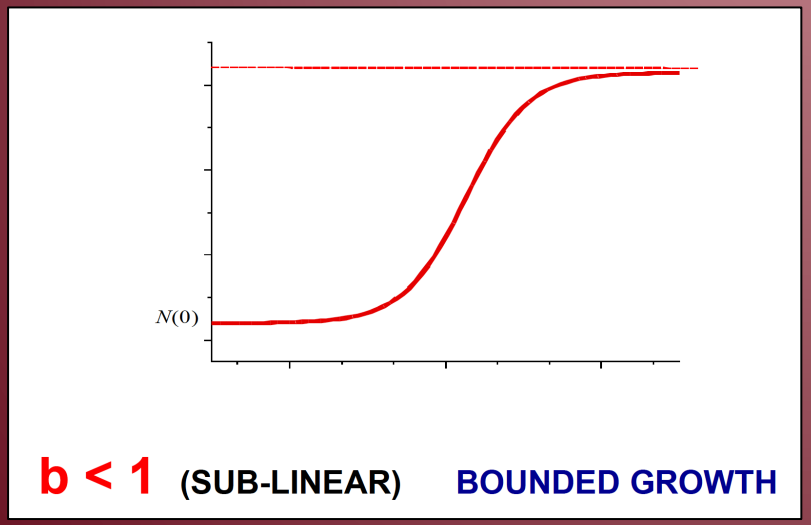
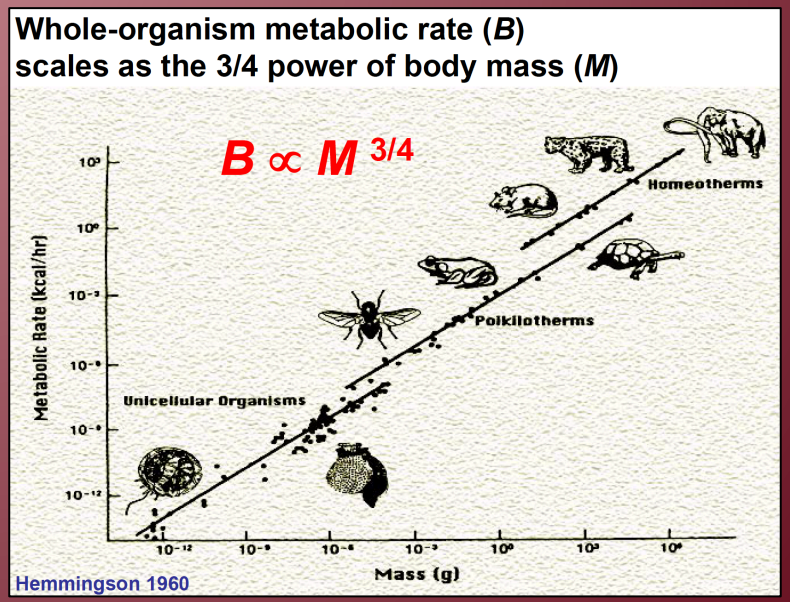
How it Works: Understanding Growth and Power-Laws

- Biological growth (life): Sigmoidal
  - Bounded: Reaches a certain point (maturity) and stops
  - Decreasing returns to scale, the bigger you are the less you need (per capita)
    - **Power-law**: As body size doubles metabolic rate only increases 75% (M -1/4) – Sub-linear scaling





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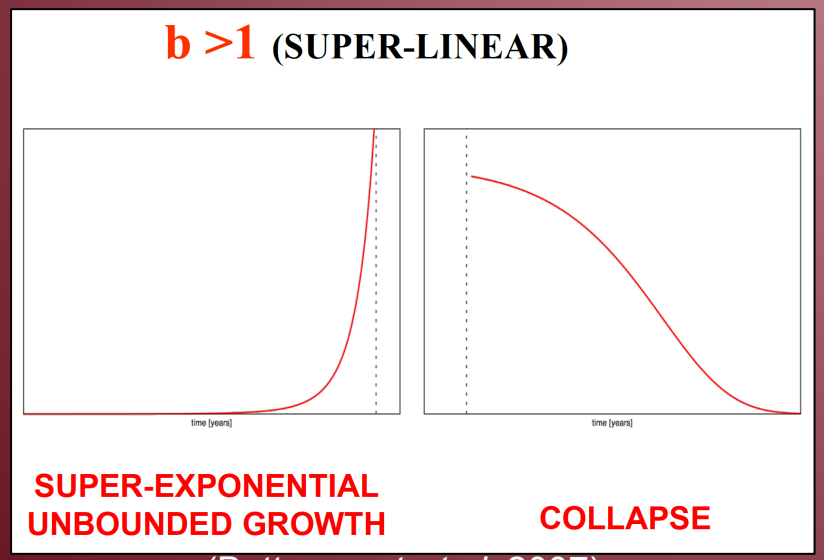
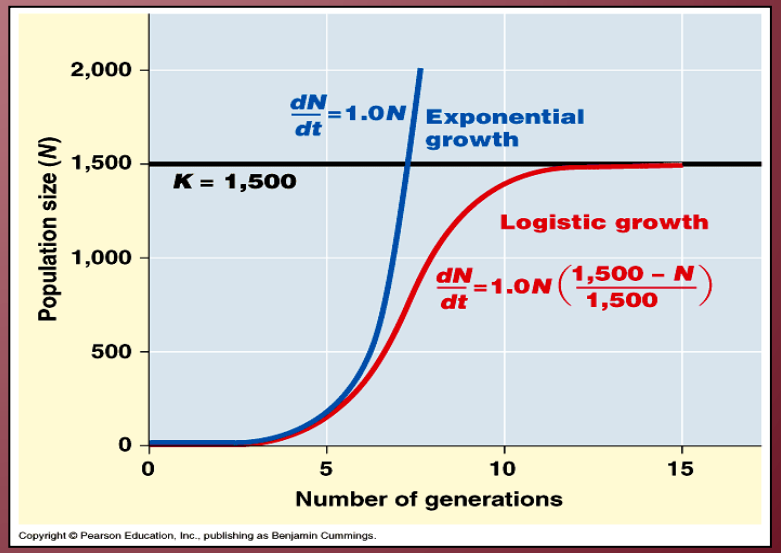
How it Works: Super-Linear Growth

- Unbounded, exponential growth
- Increasing returns to scale: The more you put in the more you receive (per capita)
- Relies on innovation and wealth creation to sustain
  - If not, stagnation leads to collapse
- Examples: a virus, computer technology, population…



(Bettencourt *et al*. 2007)



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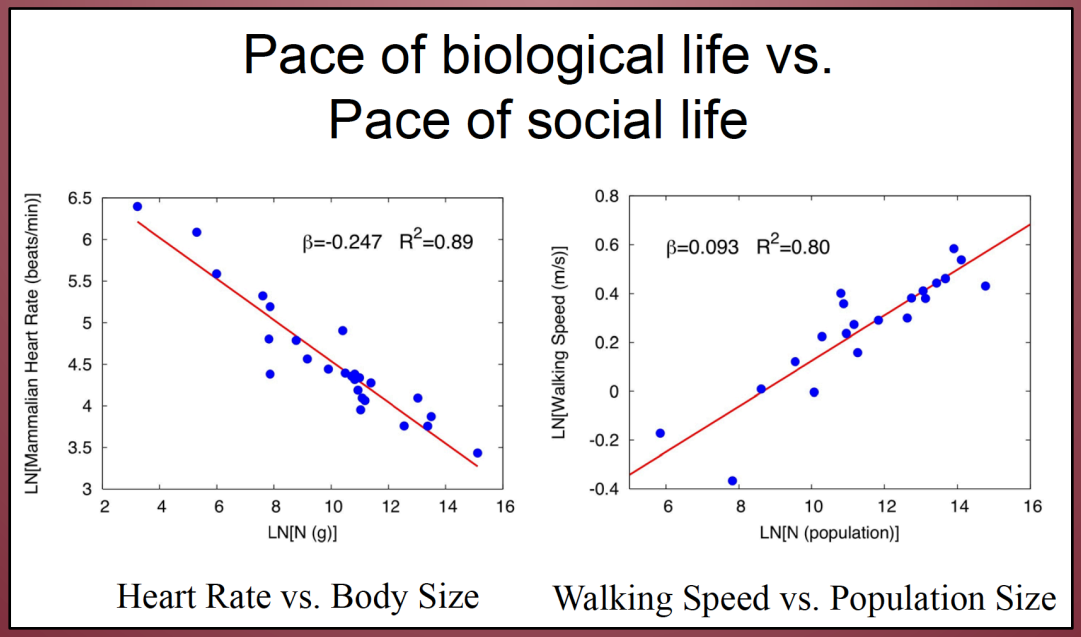
Cities vs. Biology

- World population growing exponentially:
  - 1500 – 400 million
  - 1900 – 1.6 billion
  - Today – 7 billion
- Urban populations growing exponentially:
  - **2050** – 75% of world population will live in cities



(Bettencourt *et al*. 2007)

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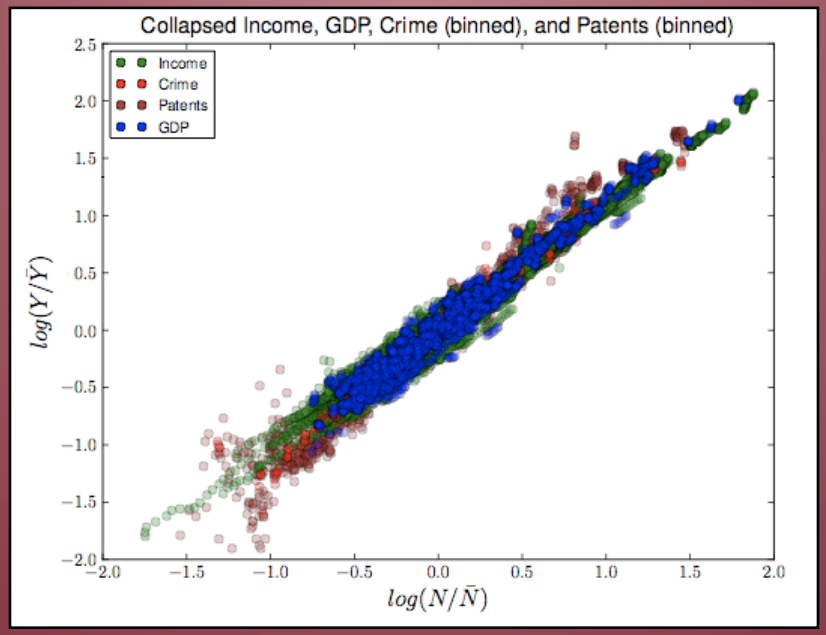
A Power-Law: The '15% Rule'

- Doubling the population of a city creates a systematic increase of all social and economic proxies by about 15% (β ≈1.2 >1) = increasing returns (per capita growth)
  - Income, wealth, housing cost, patents/innovations, 'creatives', production, consumption, crime, pollution, waste, disease, etc….



All scale in super-linear fashion; all are interconnected (Bettencourt and West 2010)

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Significance in Economic Terms

- Deepak Lal (1998): Extensive vs. Intensive growth
  - **Extensive** (Sub-linear → linear '*pari passu*')
    - Relies on economies of scale
    - No per capita growth or increasing returns
  - **Intensive** (per capita growth; super-linear)
    - Smithian (division of labor, competition, markets)
    - Promethean (innovation, technology, exponential)
- Constantinos A. Doxiadis (1968): *Ekistics*
  - **Dynamic** growth rate (Pop., GDP): 0.6 - 1.2% p.a.
    - Static growth < 0.6% p.a. – 'steady state'

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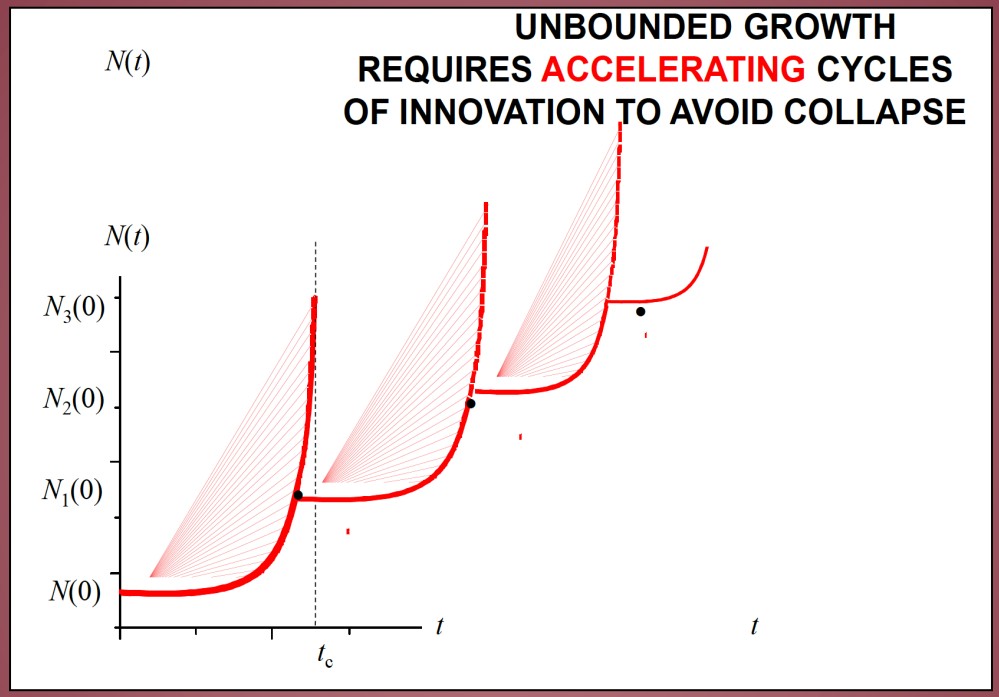
Avoiding Collapse…



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.

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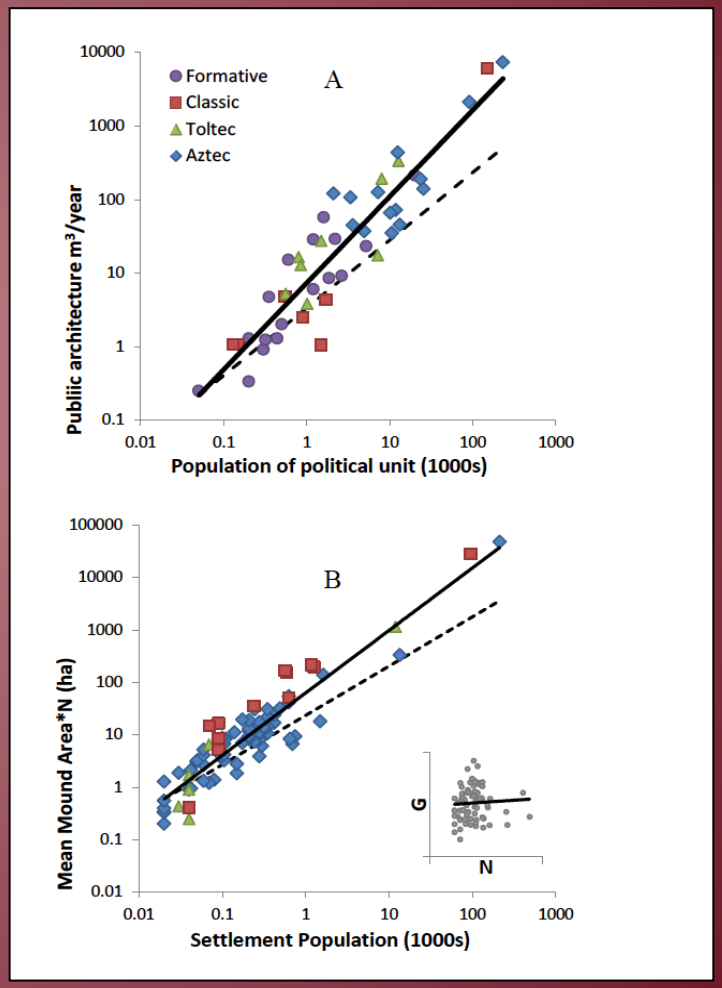
Application in the Ancient World?

- Pre-Hispanic Basin of Mexico (1150 BC - AD 1500)
- Survey data: 4,000+ sites
  - 1960 – 1975
- All settlement types explored
- Population densities scaled against public monument volume (speed) and mound (house) area
- Shows super-linear scaling and increasing returns – the larger the more productive



(Bettencourt 2013)

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Implications for Ancient Rome?

- Estimated population of Rome:
  - **200 BC** – 150,000 free; *200,000* total
  - **1 BC** – 650,000 free; *1,000,000* total (750k – low)
    - Hopkins 1978; Morley 1996; Lo Cascio 2001; Witcher 2005

- Population doubles *twice* in this period:
  - **Dynamic** population growth occurring: 0.74% p.a.
  - Following 15% rule = Theoretical +30% rise in social and economic returns

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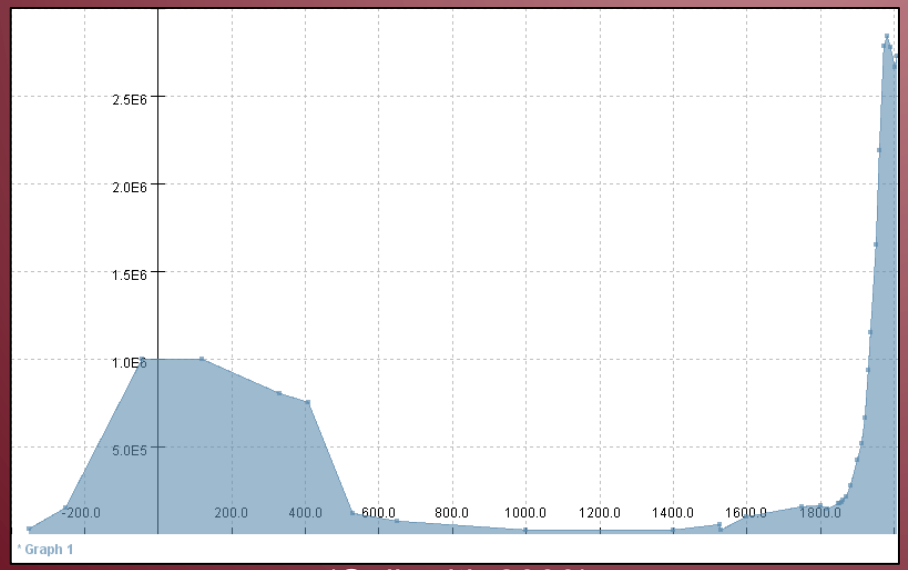
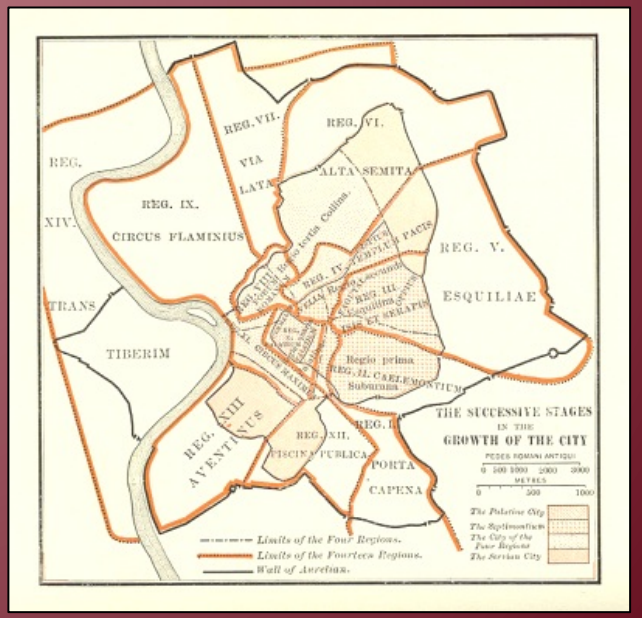
After Augustus…

- Population stops *growing* – stabilizes around 1 million
- Physical size of urban core remains relatively stable
  - *Pomerium* and tax border
  - Augustan *regiones* and Aurelian Wall (3rd C. AD)
  - Regionary Catalogues (4th C. AD)



(Galbraith 2009)



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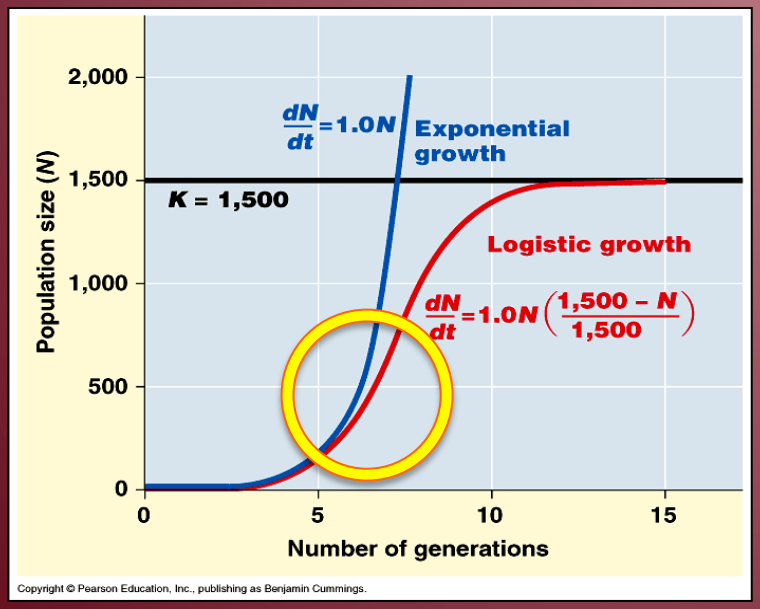
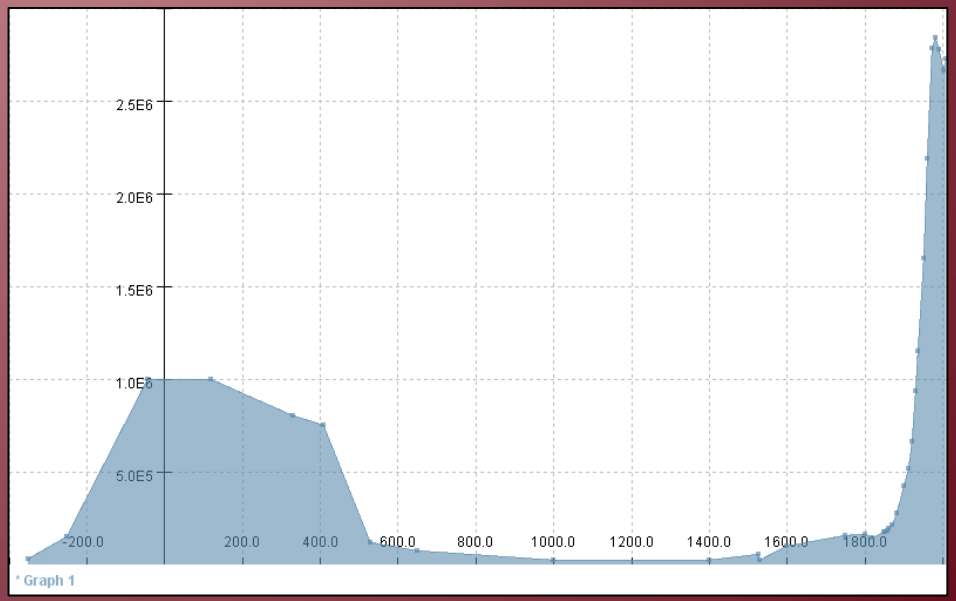
Growth and Restraints

- The Verhulst Equation (1838) - inspired by Thomas Malthus
  - Logistic equation; carrying capacity (K); bottleneck of resources
  - Self-limiting growth of biological population after initial 'boom'
- Sigmoidal vs. Exponential growth
  - How to untangle?





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The Big Question(s)

- Did Rome (and perhaps other ancient cities) grow sigmoidally, until reaching population 'maturity' and maxing out carrying capacity?

Or….

- Did Rome fail to innovate fast enough to sustain exponential, super-linear growth – thus leading to stagnation and eventual decline?
- Does Rome prove the Bettencourt/West model *OR* is it an exception to the rule?
- How can we determine this?

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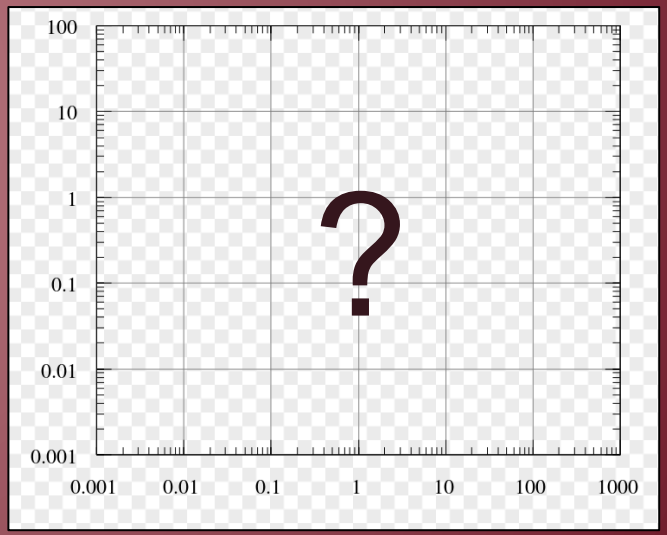
Scaling Relationships in Rome?

- Population in Republic scaled against socio-economic proxies:
  - Housing prices/units
  - Middling income
  - Fuel consumption (aggregate p.a.)
  - Food consumption (aggregate p.a.)
  - Market space (m3/year)
  - Taxation (aggregate p.a.)
  - Tombs (cost and size)
  - Skeletal size
  - Number of *collegia* formed (p.a.)
  - Number of occupations
  - Crimes/prison space
  - And many more, BUT…



NO Diachronic Dataset for Republican Rome

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Looking Outside of Rome: Italy

- Philip Kay (2014) *Rome's Economic Revolution*
  - Methodology:
    - Estimate GDP (income and expenditure – state and private) to gauge size of economy in 150, 100, 50 BC
    - Distribute over 'low count' of population in Republican Italy
    - Track supply and circulation velocity of currency
  - Conclusions:
    - **Real per capita GDP grew by 72% from 150-50 BC** (5 mil – 5.8 mil)
    - **GDP compound growth rate: 0.54% p.a.**
  - Significance:
    - Intensive, per capita economic growth occurring in Republic
    - Not quite 'dynamic' growth rate – 0.6% (Doxiadis 1968), but…
  - Caveats:
    - Estimations and date range (200 BC population: 3.1 mil)
    - Depends how you slice it: Greatest growth appears to be from 150-100 BC (or earlier)
    - Relies on 'low count' – what if greater pop?
    - Significance of Rome???

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Looking Outside of Rome: Empire

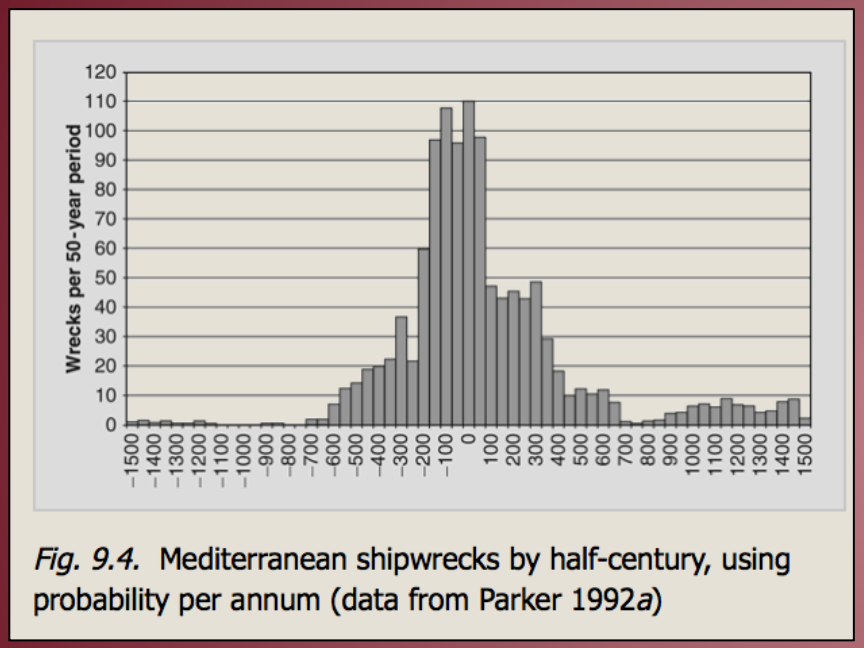
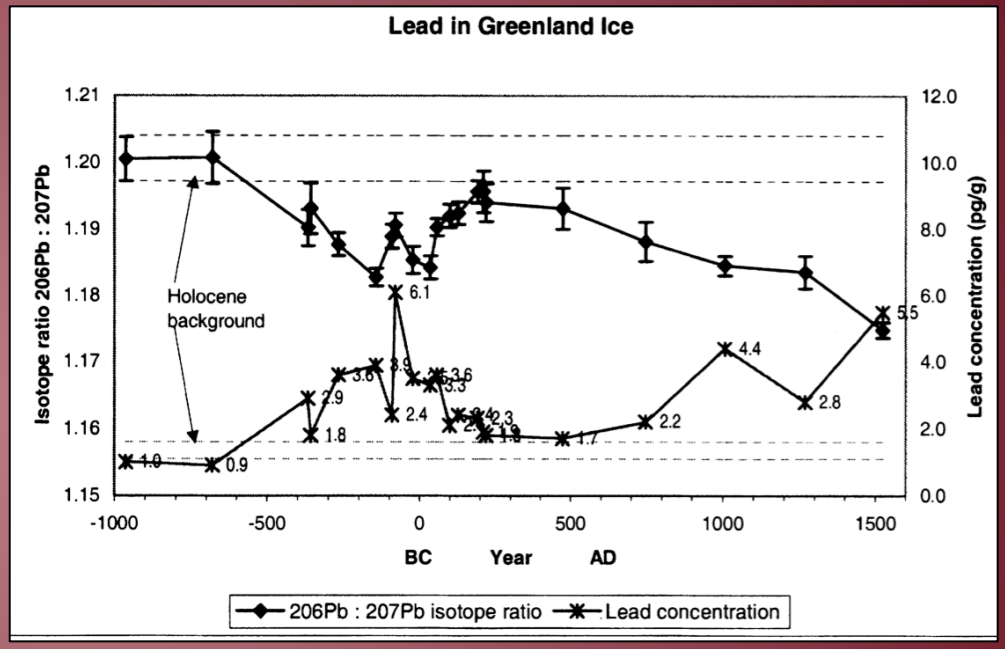


Fig. 9.4. Mediterranean shipwrecks by half-century, using probability per annum (data from Parker 1992*a*)

(Wilson 2009)



(Wilson 2002 from Rosman *et al*. 1997)

- General trends point to growth in Republican period up to a peak in late Republic/early Empire followed by stagnation (or 'steady state') in the Imperial period

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What Happened? More Questions…

- Reasons for stagnation/collapse?
  - Exogenous shock or endogenous shift?
- Is there a shift from intensive to extensive economic growth?
  - An economy of scale (expansion…) vs. increasing returns?
- Does population stagnation in city of Rome mirror general empire-wide trends in trade and production? (lack of growth)
- *The power of population* - the driver or destroyer, or both?
- Why no Promethean growth?

Answer: 2 Scenarios

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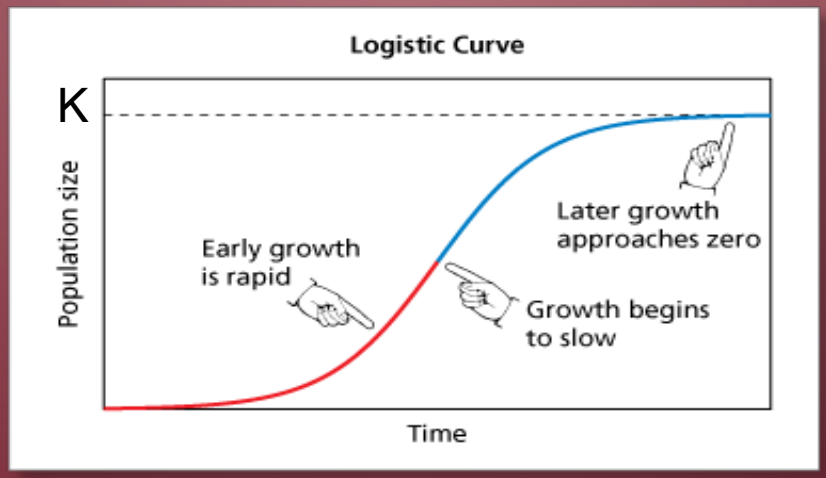
The Growth of Rome: Scenario 1

- The growth of Rome was inherently sigmoidal/logistic
- Rome's population growth followed the Verhulst Equation
  - Malthusian restraints
- Economy relied largely on *extensive* growth and economies of scale
- Political/legal institutions inherently nationalist (North 1990: NIE)
- **Significance:** Rome (and possibly other ancient cities) grew (and scale) differently than modern cities



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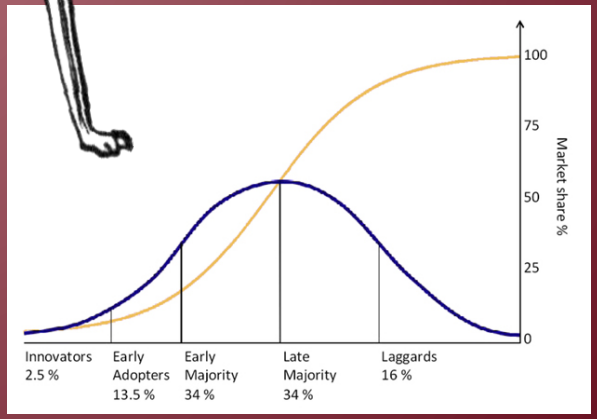
The Growth of Rome: Scenario 2

- Rome was on path to exponential, super-linear growth but could not maintain accelerating cycles of innovation
  - Bettencourt/West model

- **3rd Century BC:**
  - Water wheel/Water mill
  - Escapement
  - Chain Drive
- **2nd Century BC:**
  - Air and water pumps (3rd/2nd C. BC)
  - Bilge, screw, double action
  - Concrete, surveying tools
  - Antikythera Mechanism (late)
- **1st Century BC:**
  - Hushing and sluicing (mining)
  - Glass blowing
  - Aeolopile – Steam power…
- **Empire**
  - Technologies reach critical mass?



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Scenario 2 (cont.)

- Changing political institutions: Shift from contract to nationalist economy in Imperial period (Malmendier 2010):
  - Switch from private entrepreneurs (*publicani*) to bureaucrats
  - Demise of the *societas publicanorum* and *collegia* (corporations)
  - *Publicani* suppressed and proscribed - competition hindered
  - Resources, innovation/technology controlled by the Emperor…

- 15% Rule = 15% rise in entropic elements - lack of innovation and failure to cope
  - Disease
  - Pollution
  - Poor land/water management (Frontinus; Sermonti 1968)

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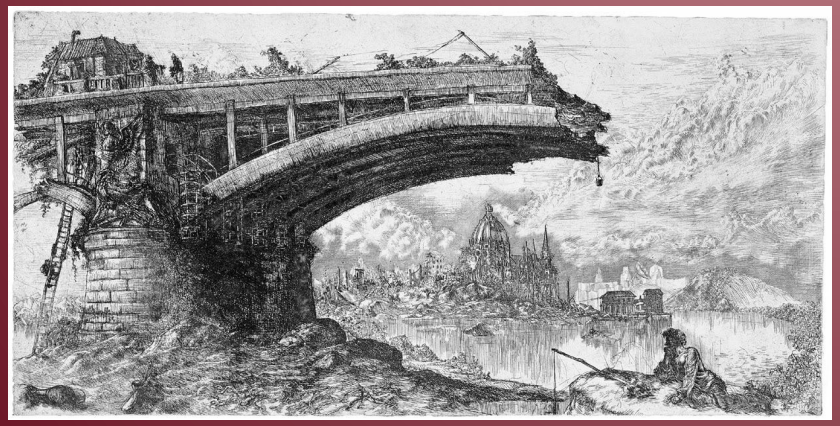
Scenario 2: Significance and Implications

- Rome grew (and scales) the same as modern cities, however, it was not able to sustain this growth due to a failure to innovate at an accelerating rate:
  - Shift from intensive economic growth (in Republic) to extensive (in Empire)
  - Lack of innovation due to changes in political institutions and a failure to sustain population growth
- Lessons to be learned?



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Conclusions and Further Work

- Urban scaling provides a valuable new approach to examining correlations between urbanization, population, and economy in the Roman/ancient world
  - Can help identify type(s) of demographic and economic growth and change over the longue durée
  - A reason to count!
  - A way to compare/contrast modern and ancient settlements

- **Further Work:**
  - SFI, Urbnet
  - **Survey Data!**
  - On-going excavations…
  - Re-evaluation of existing materials

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