RETHINK 2018

Prof. Geoffrey West
Distinguished Professor and former President The Santa Fe Institute (SFI) Santa Fe, New Mexico and Oxford University

EPRA

The theory of scale – application on the realities and current challenges of the listed real estate

DEVELOPING A SCIENCE OF CITIES

GROWTH, INNOVATION, AND THE ACCELERATING PACE OF LIFE

GEOFFREY WEST

SANTA FE INSTITUTE

OXFORD UNIVERSITY

WE LIVE IN AN EXPONENTIALLY EXPANDING SOCIO-ECONOMIC UNIVERSE!!

1800 ***< 4% THE US POPULATION WAS URBAN***

2014 ***> 80% URBANISED***

2006 ***> 50% WORLD'S POPULATION URBANISED***

2050 ***> 75% URBANISED***

EQUIVALENT TO URBANISING OVER ONE MILLION PEOPLE EVERY WEEK FROM NOW TILL 2050

EQUIVALENT TO URBANISING OVER ONE MILLION PEOPLE EVERY WEEK FROM NOW TILL 2050

OR…….TO ADDING A NEW YORK METROPOLITAN AREA EVERY TWO MONTHS FROM NOW TO 2050

EQUIVALENT TO URBANISING OVER ONE MILLION PEOPLE EVERY WEEK FROM NOW TILL 2050

OR…….TO ADDING A NEW YORK METROPOLITAN AREA EVERY TWO MONTHS FROM NOW TO 2050

OR……. A BERLIN EVERY TWO WEEKS

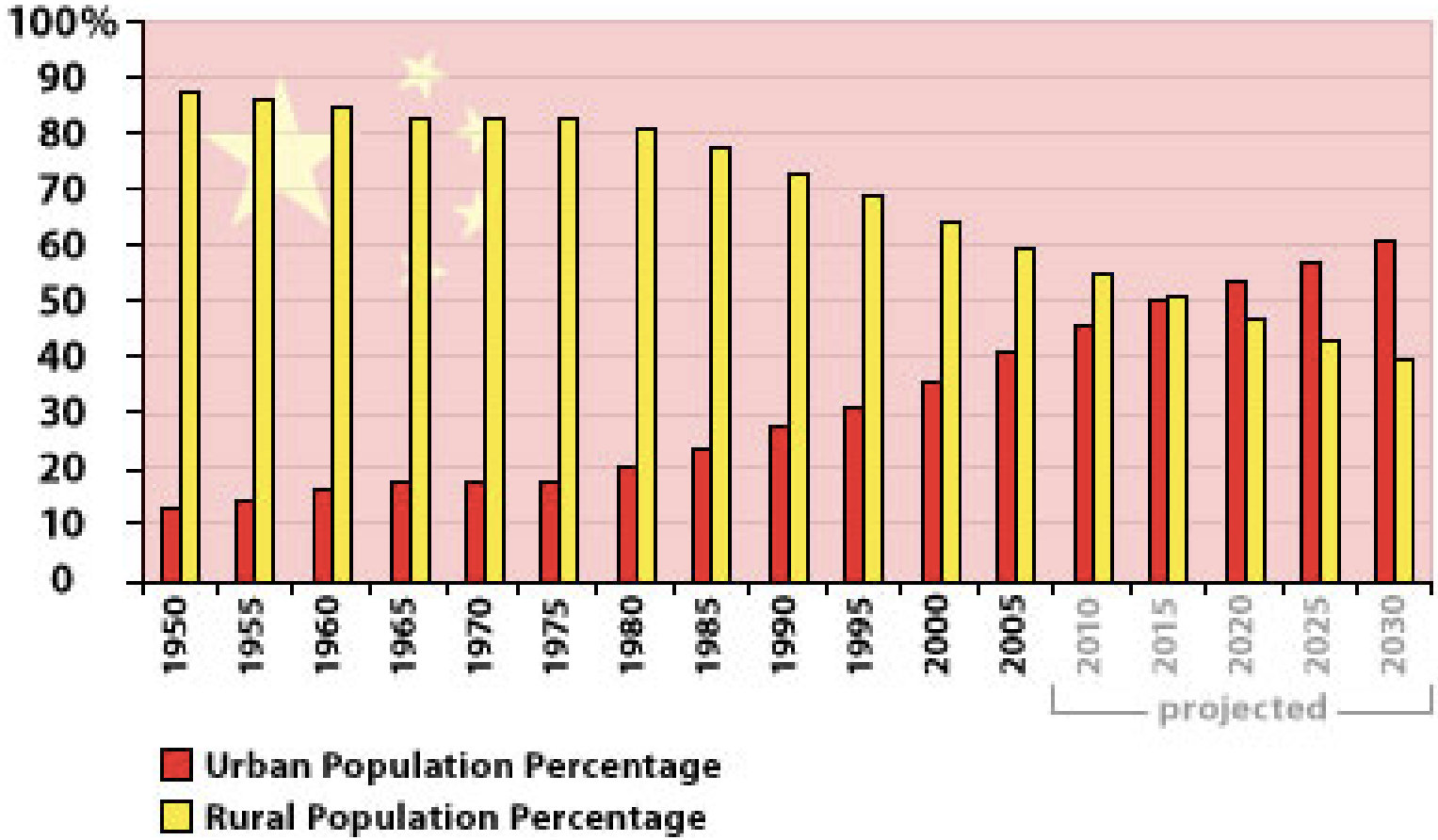
EQUIVALENT TO URBANISING OVER ONE MILLION PEOPLE EVERY WEEK FROM NOW TILL 2050

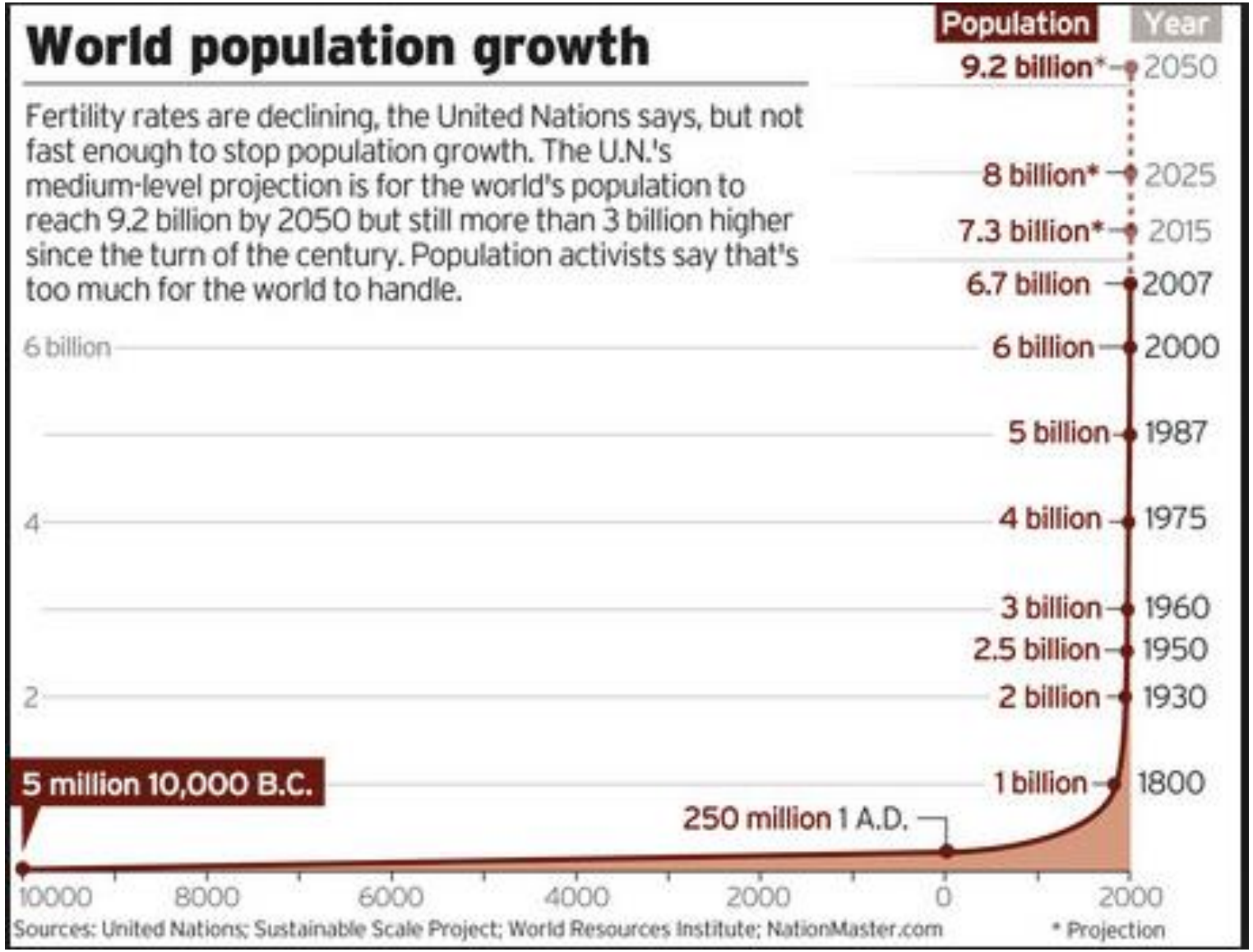
OR…….TO ADDING A NEW YORK METROPOLITAN AREA EVERY TWO MONTHS FROM NOW TO 2050

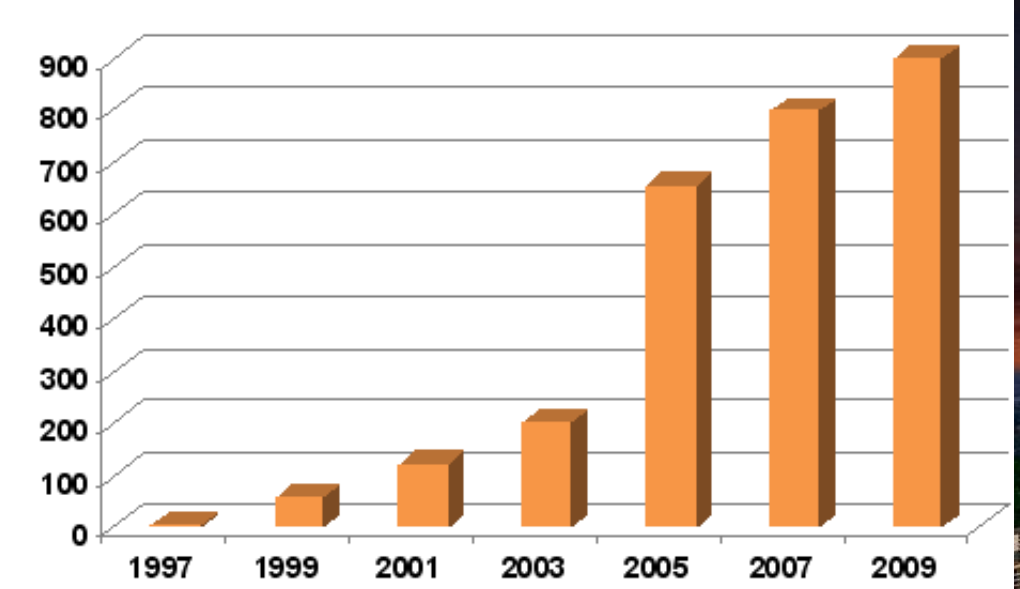
OR……. A BERLIN EVERY TWO WEEKS

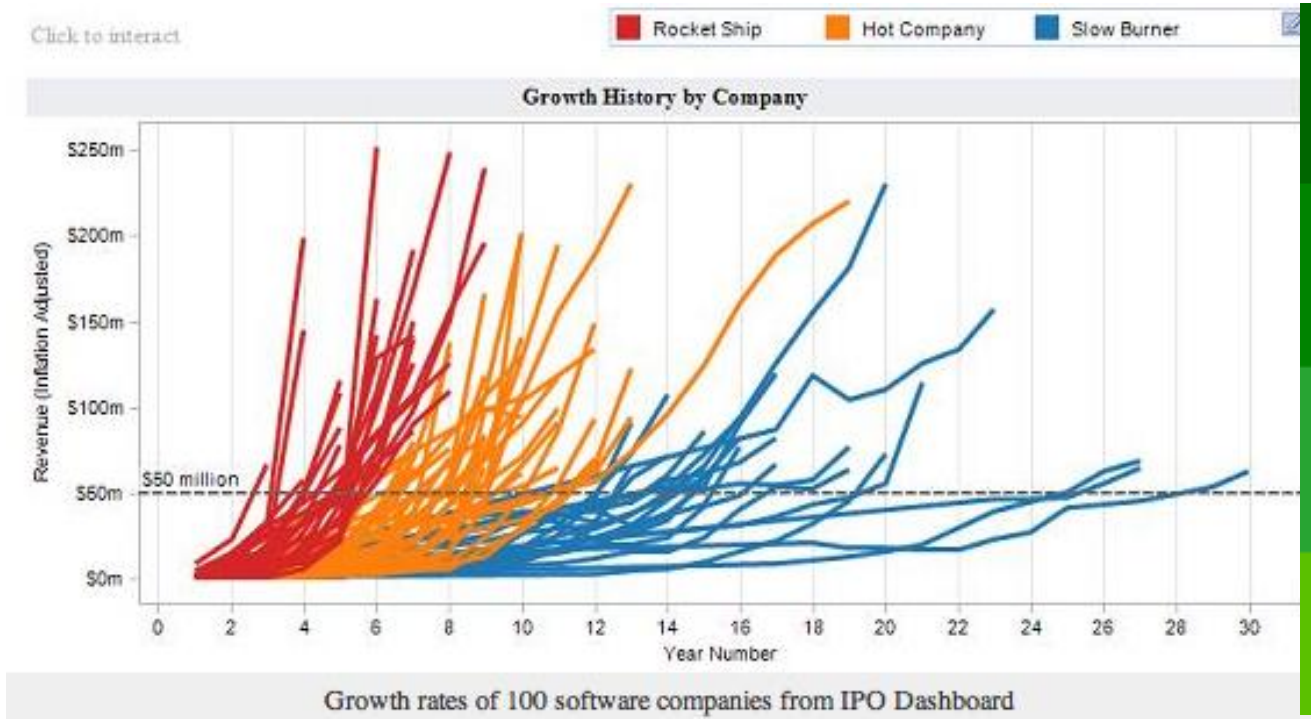
OR……..A DENMARK EVERY MONTH!

CHINA URBAN/RURAL POPULATION GROWTH 1950-2030

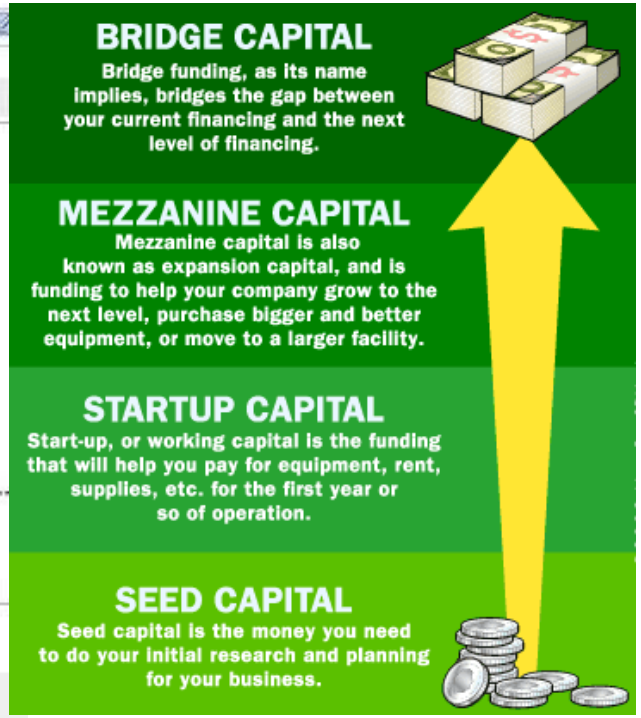



World population growth
Fertility rates are declining, the United Nations says, but not fast enough to stop population growth. The U.N.'s medium-level projection is for the world's population to reach 9.2 billion by 2050 but still more than 3 billion higher since the turn of the century. Population activists say that's too much for the world to handle.
Population
Year
9.2 billion* 2050
8 billion* 2025
7.3 billion* 2015
6.7 billion 2007
6 billion 2000
5 billion 1987
4 billion 1975
3 billion 1960
2.5 billion 1950
2 billion 1930
1 billion 1800
6 billion
4
2
5 million 10,000 B.C.
250 million 1 A.D.
10000
8000
6000
4000
2000
0
2000
Sources: United Nations; Sustainable Scale Project; World Resources Institute; NationMaster.com
* Projection





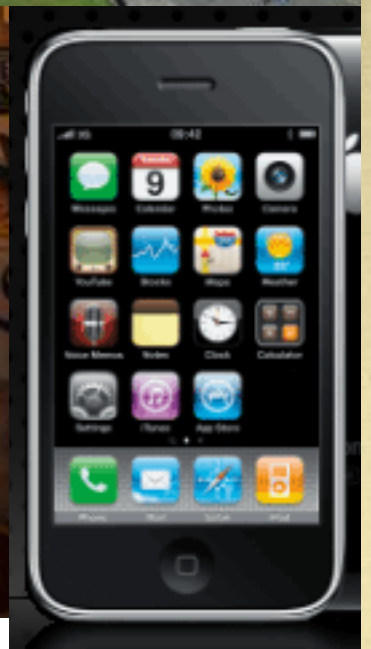
Growth rates of 100 software companies from IPO Dashboard



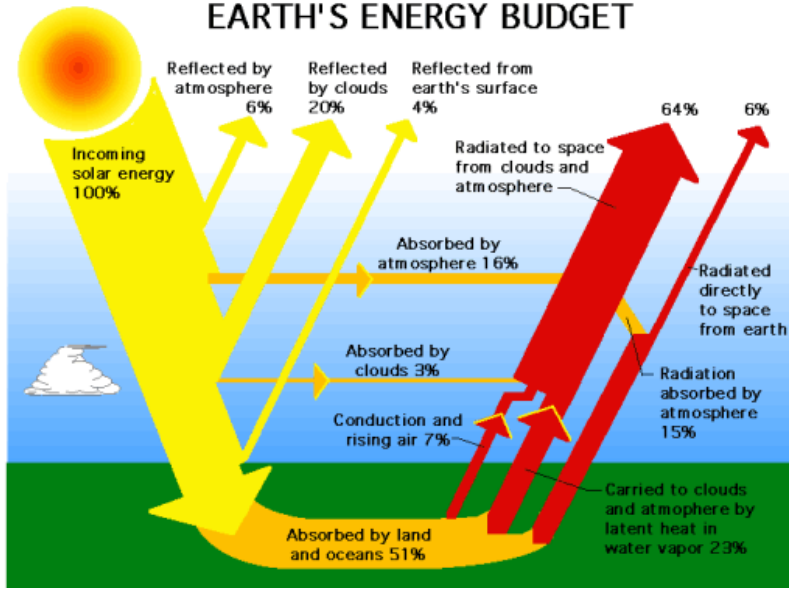

FATE OF OUR PLANET IS
the fate of our cities


lonelyplanetimages.com

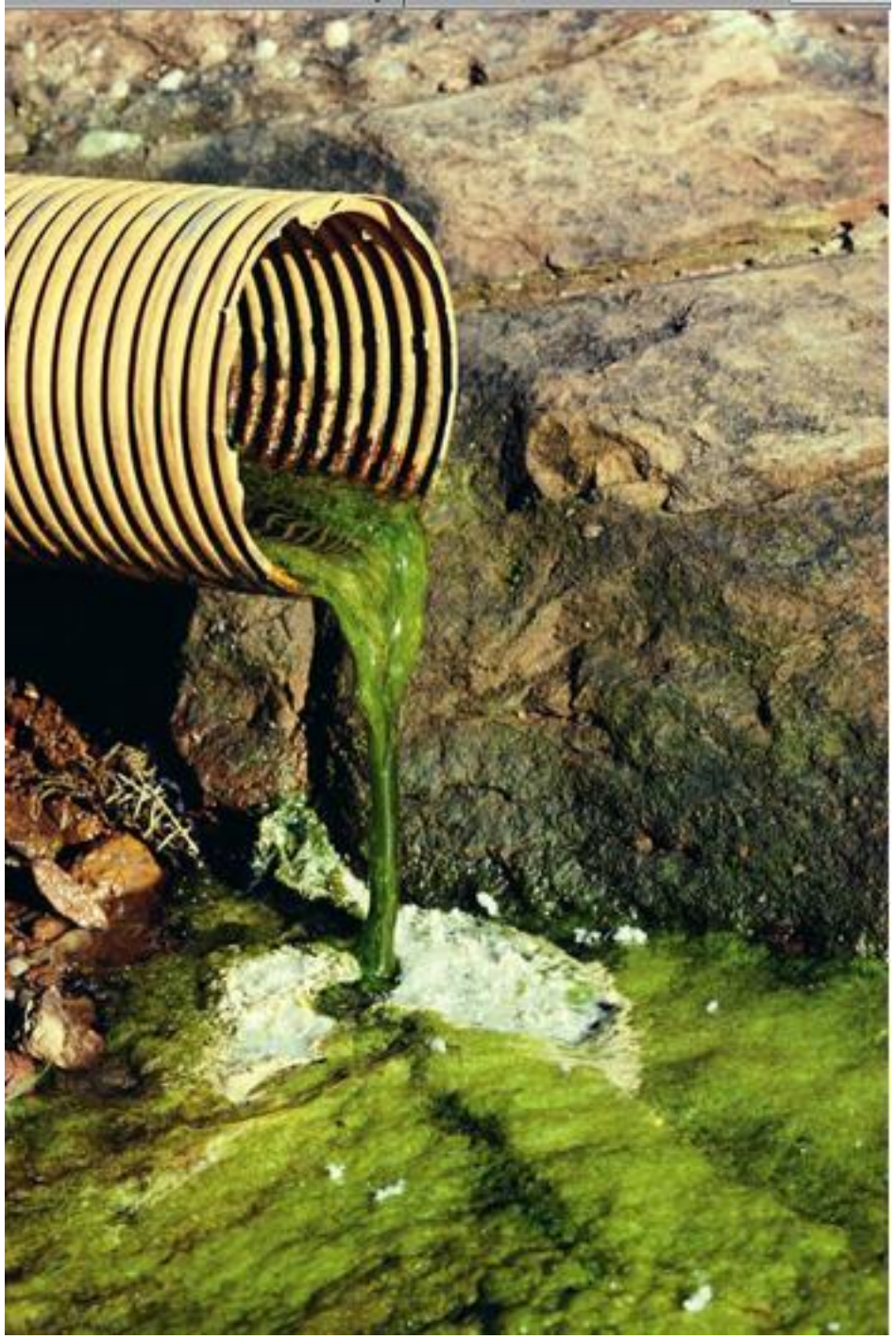

THALDEN•BOYD ARCHITECTS




Missa Papæ Marcelli Cum Sex vocibus. 48
Yrie elei


EARTH'S ENERGY BUDGET
Reflected by atmosphere 6%
Reflected by clouds 20%
Reflected from earth's surface 4%
64%
6%
Incoming solar energy 100%
Radiated to space from clouds and atmosphere
Absorbed by atmosphere 16%
Radiated directly to space from earth
Absorbed by clouds 3%
Radiation absorbed by atmosphere 15%
Conduction and rising air 7%
Carried to clouds and atmophere by latent heat in water vapor 23%
Absorbed by land and oceans 51%


南
9




Evening Standard
Classified
MASSIVE INCREASE IN KNIFE CRIME SURVEYS
Evening Standard

London After Climate Change?


M·AGRIPPA·L·F·COS·TERTIVM·FECIT

ENERGY & RESOURCES
(METABOLISM, INFRASTRUCTURE)

vs.

INFORMATION
(GENOMICS, INNOVATION)

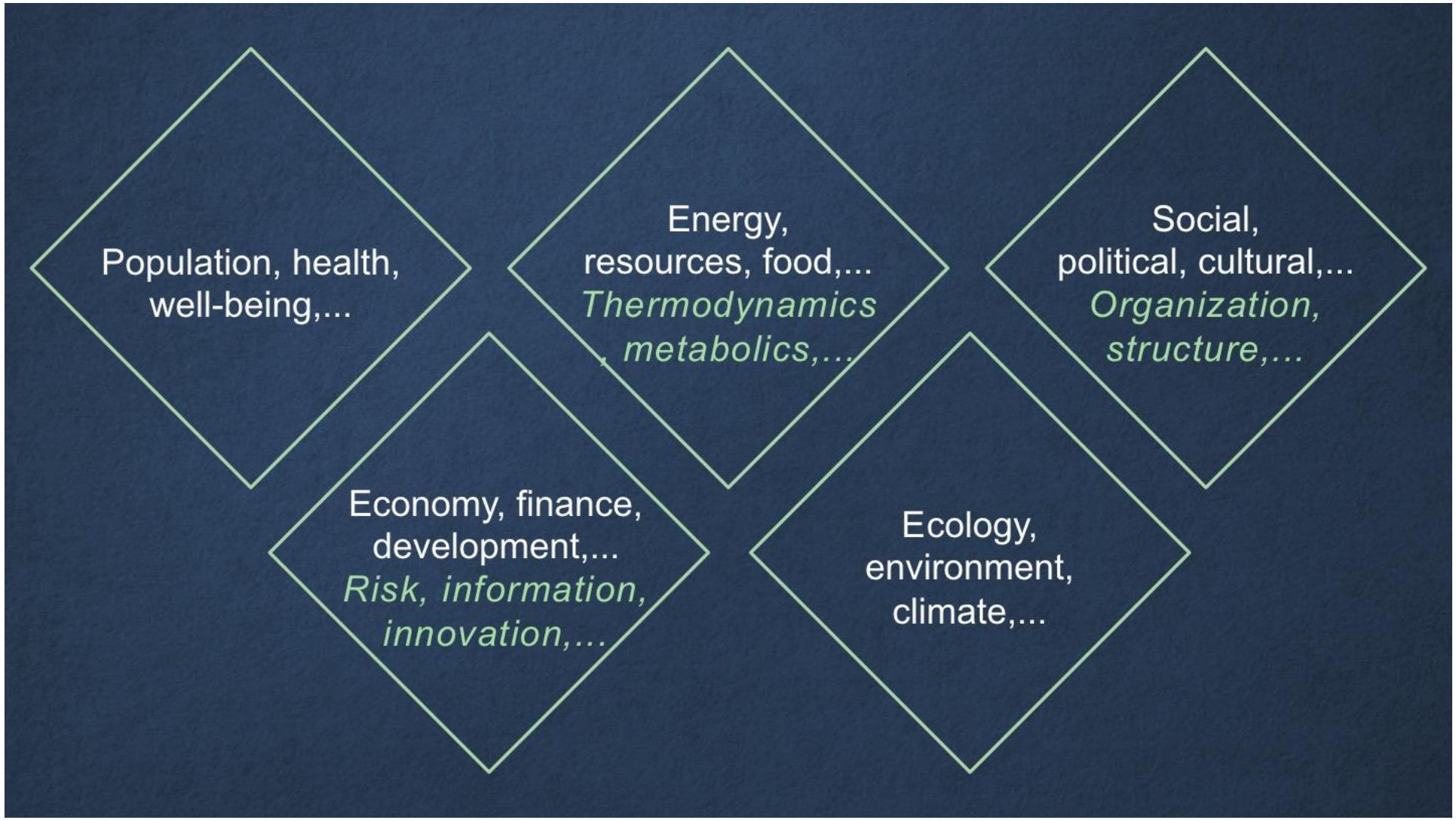
URGENTLY NEED A QUANTITATIVE, PREDICTIVE SCIENCE OF CITIES

RESILIENCE

EVOLVABILITY

GROWTH

SCALABILITY


Population, health, well-being,...
Energy, resources, food,... Thermodynamics, metabolics,...
Social, political, cultural,... Organization, structure,...
Economy, finance, development,... Risk, information, innovation,...
Ecology, environment, climate,...

THESE ARE NOT INDEPENDENT

They are all highly coupled, inter-related, multi-scale *complex adaptive systems*.


CAN'T WAIT FOR THE ROAD
TO BE WIDENED!


CAN'T WAIT FOR THE ROAD
TO BE WIDENED!


FINALLY!

WHY DO WE STOP GROWING?

WHY DO WE AGE?

WHY DO WE LIVE ~100 YEARS AND NOT 1000, OR 2-3 YEARS LIKE A MOUSE?

WHERE DOES A TIME-SCALE OF 100 YEARS COME FROM?

HOW IS IT GENERATED FROM FUNDAMENTAL MICROSCOPIC MOLECULAR TIME-SCALES OF GENES AND RESPIRATORY ENZYMES?

WHY DO WE SLEEP ~8 HOURS A DAY AND NOT 15 LIKE MICE AND BABIES OR JUST 3 LIKE ELEPHANTS?

WHY DO ALL COMPANIES EVENTUALLY DISAPPEAR, LIKE WE DO, WHEREAS (ALMOST) ALL CITIES SURVIVE?

WHY DO CITIES (AND ECONOMIES) KEEP GROWING WHEREAS ALL COMPANIES STOP?


TWA
TWA
TWA
TWA


GM


LEHMAN BROTHERS

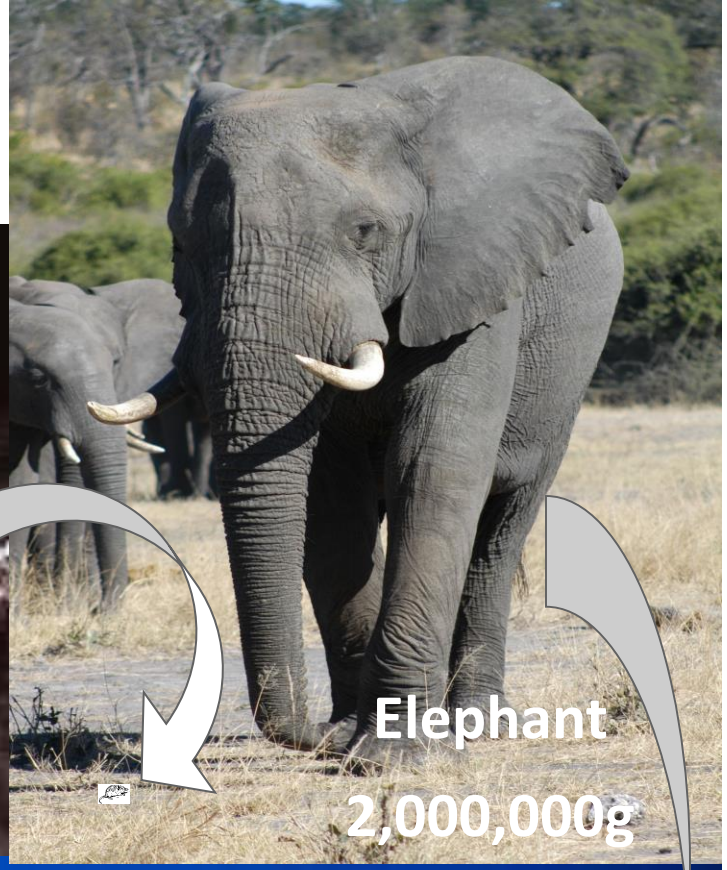

This Business
is now
CLOSED

ARE CITIES AND COMPANIES JUST VERY LARGE ORGANISMS SATISFYING THE LAWS OF BIOLOGY?

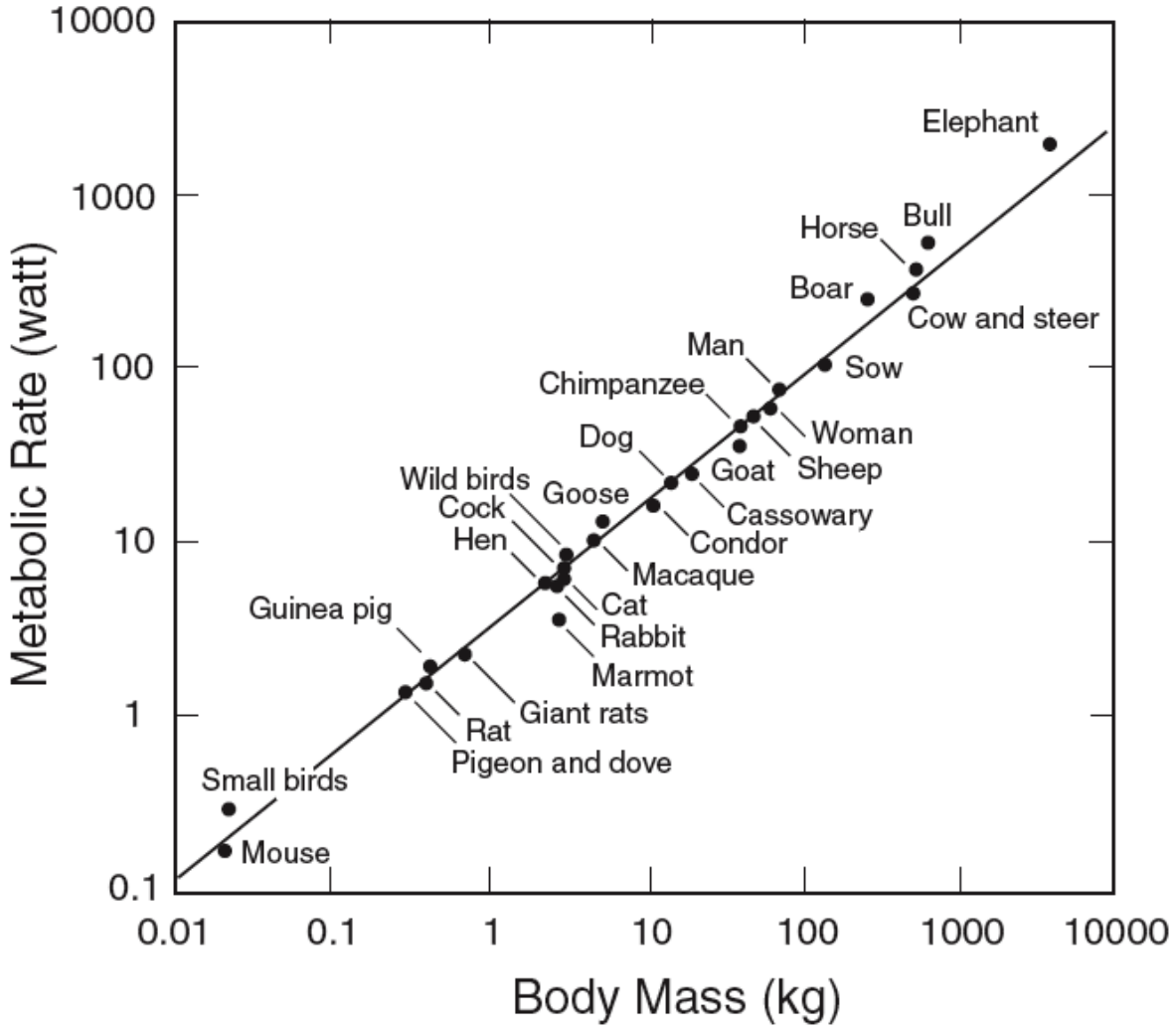
WHY DOES THE PACE OF LIFE CONTINUE TO ACCELERATE?

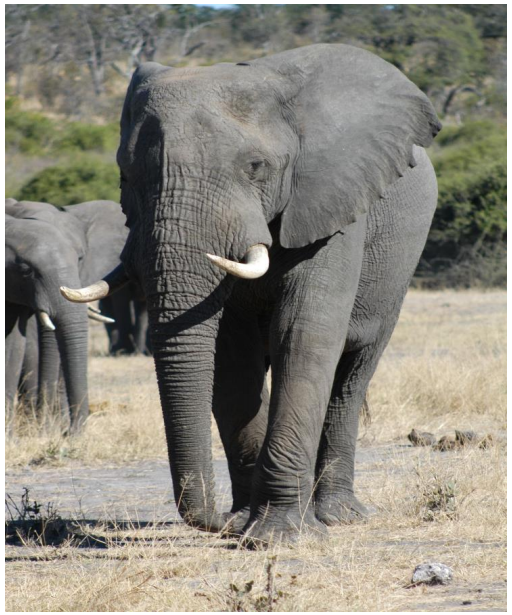
IS ANY OF THIS SUSTAINABLE?


Shrew
2g


Elephant
2,000,000g


Blue Whale
200,000,000g

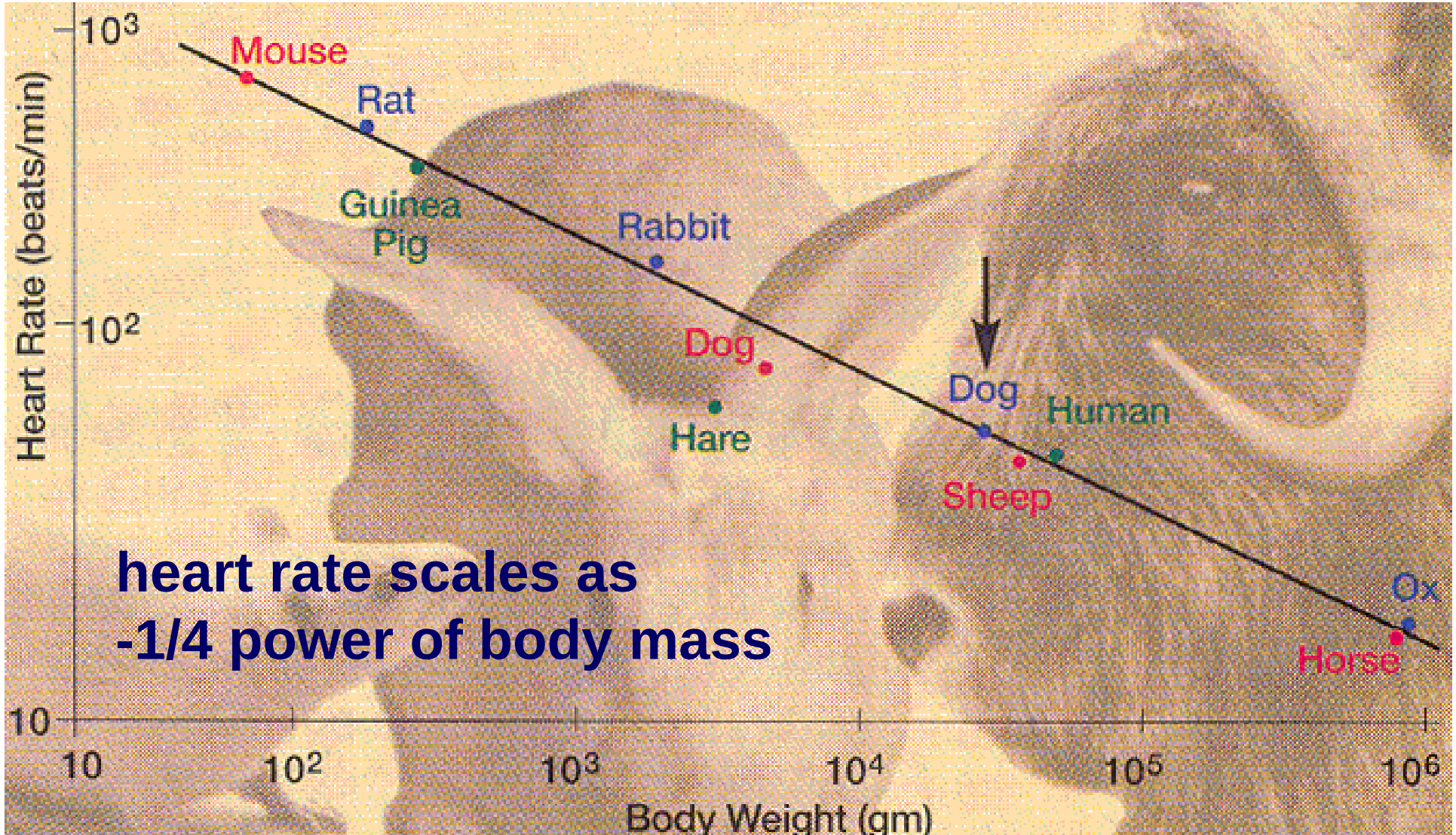

Metabolic Rate (watt)
10000
1000
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
Body Mass (kg)
Elephant
Horse
Bull
Boar
Cow and steer
Man
Sow
Chimpanzee
Woman
Dog
Goat
Sheep
Wild birds
Goose
Cassowary
Cock
Hen
Condor
Macaque
Cat
Guinea pig
Rabbit
Marmot
Giant rats
Rat
Pigeon and dove
Small birds
Mouse



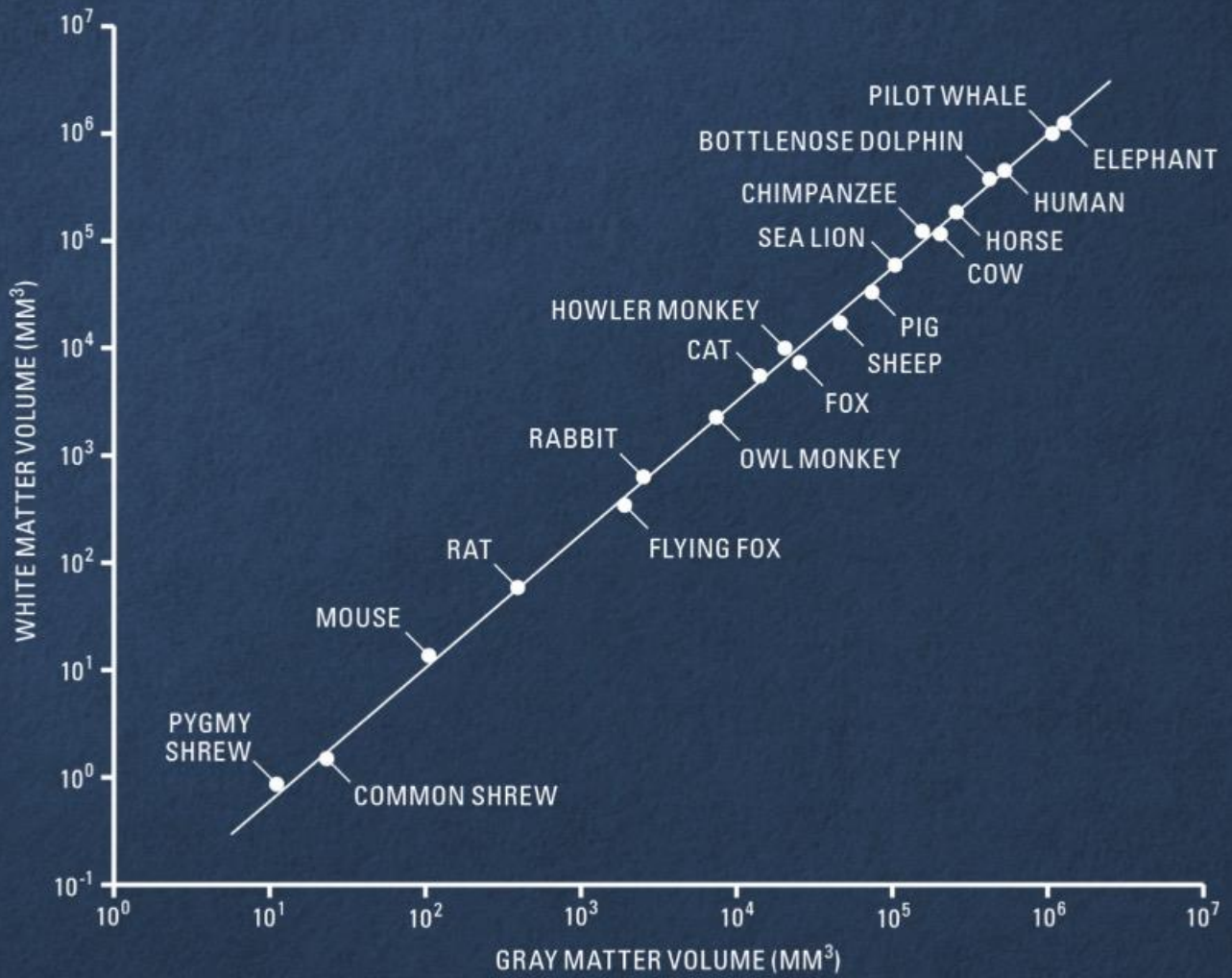
EXTRAORDINARY SYSTEMATIC ECONOMY OF SCALE (THE BIGGER YOU ARE, THE LESS NEEDED PER "CAPITA")

SIMILAR SCALING HOLDS TRUE FOR ALL PHYSIOLOGICAL PROCESSES AND LIFE HISTORY EVENTS OVER THE ENTIRE SPECTRUM OF LIFE

Metabolic rate sets the pace of life
Small animals live fast and die young



WHITE AND GRAY MATTER OF BRAINS



Slopes (exponents) are typically sub-linear and simple multiples of ¼

“quarter-power scaling”

LIFESPAN

$$T \sim M^{1/4}$$

IF HEART-RATE (NUMBER OF BEATS PER SEC.)

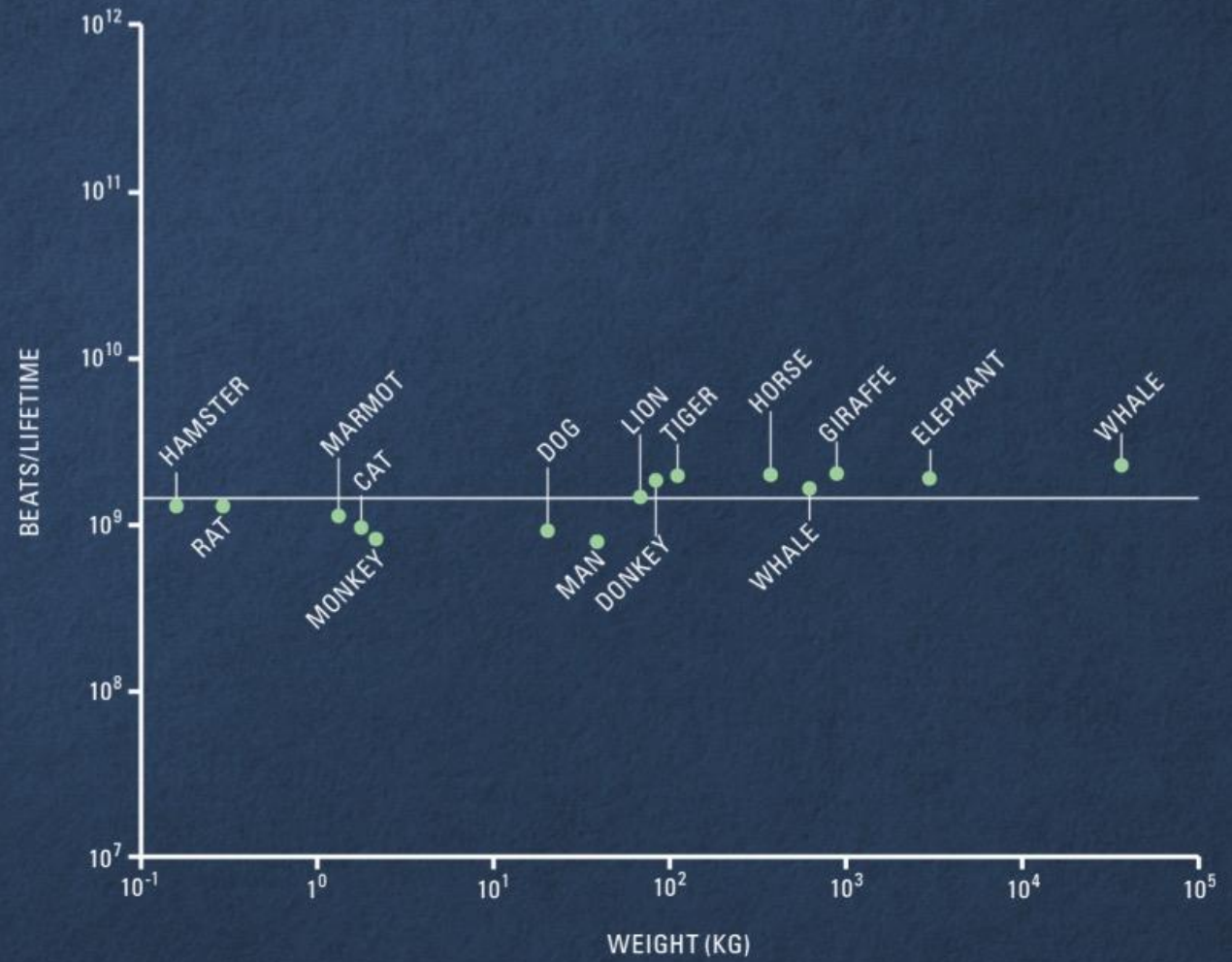
$$\sim M^{-1/4}$$

⇒ TOTAL NUMBER OF HEART-BEATS IN A TYPICAL LIFE-TIME IS INDEPENDENT OF SIZE!

$$\approx 1.5 \times 10^9$$

EACH ANIMAL SPECIES REGARDLESS OF SIZE HAS APPROXIMATELY THE SAME NUMBER OF HEART-BEATS IN ITS LIFE-TIME (ROUGHLY 1 BILLION)

NUMBER OF HEARTBEATS PER LIFETIME OF ANIMALS



Slopes (exponents) are typically sub-linear and simple multiples of ¼

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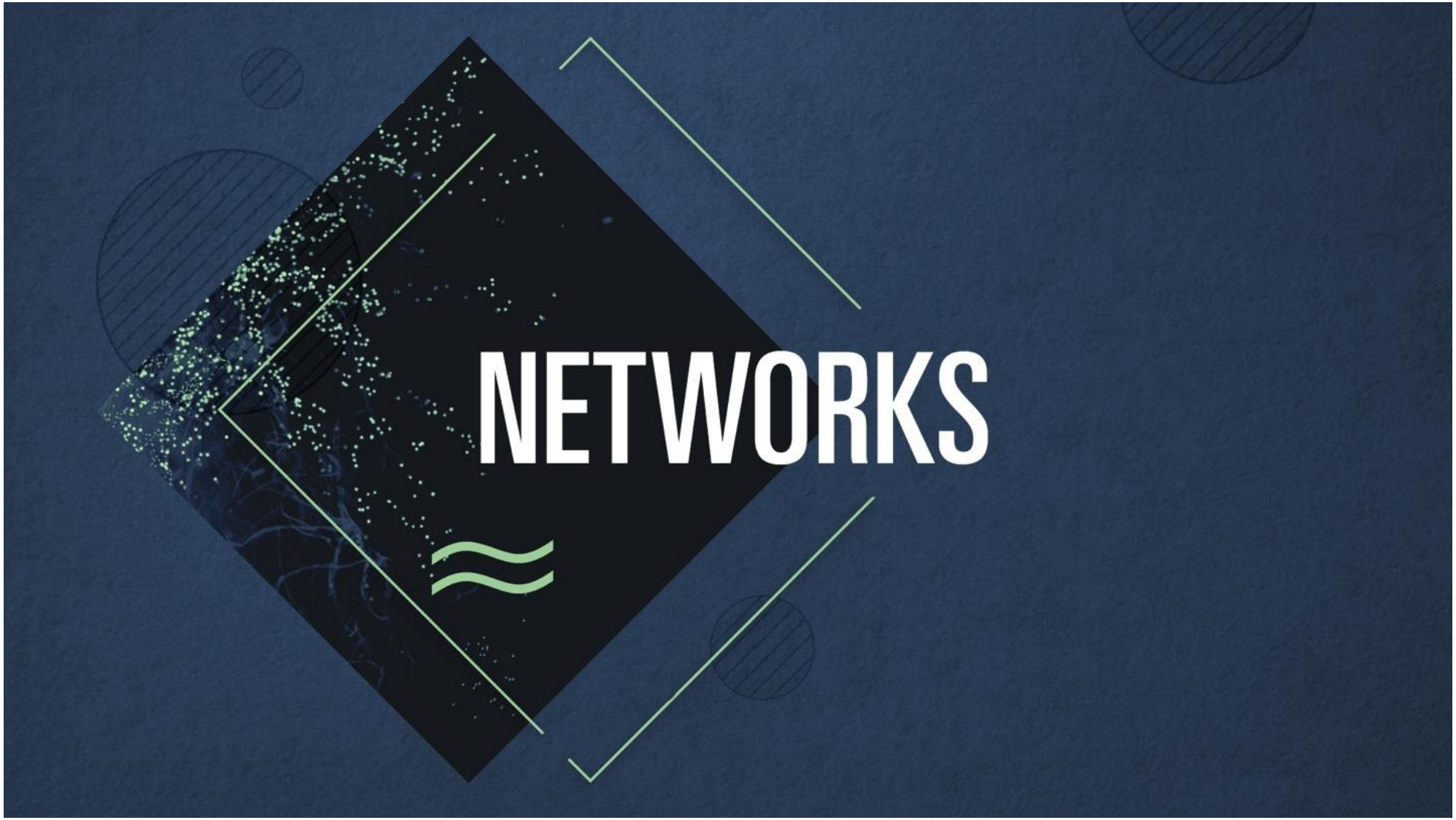
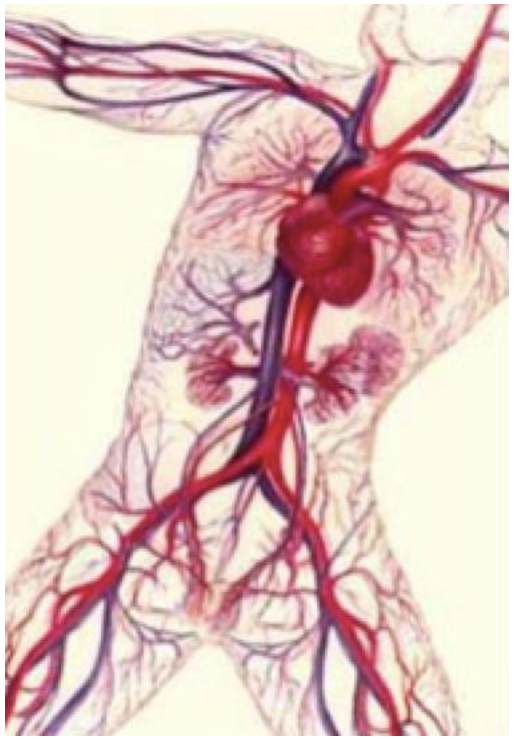
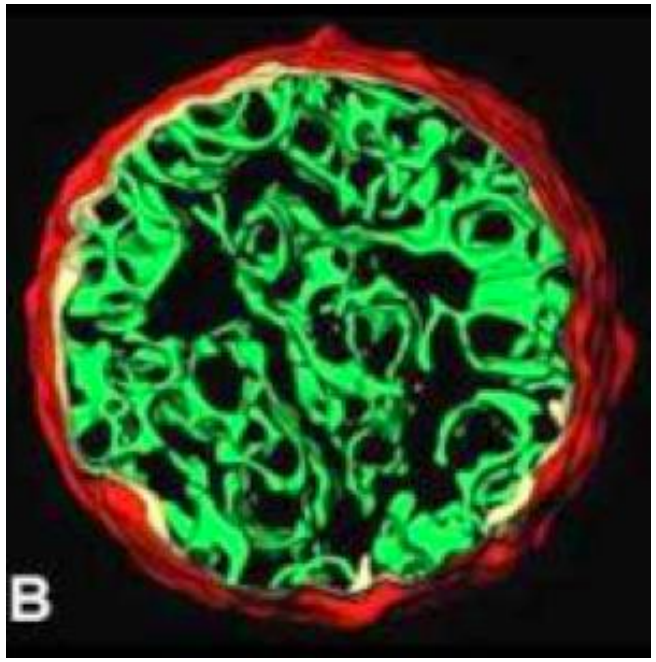
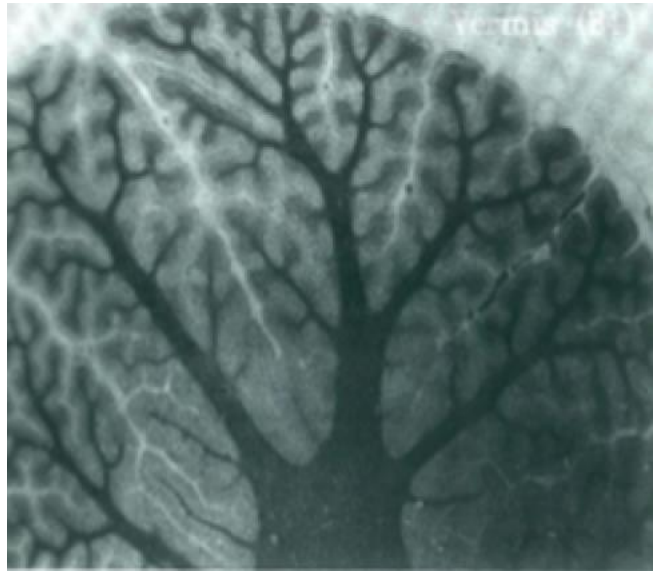
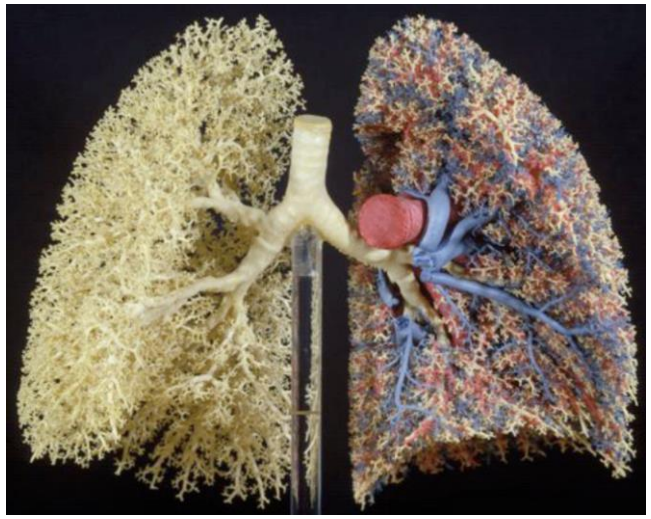
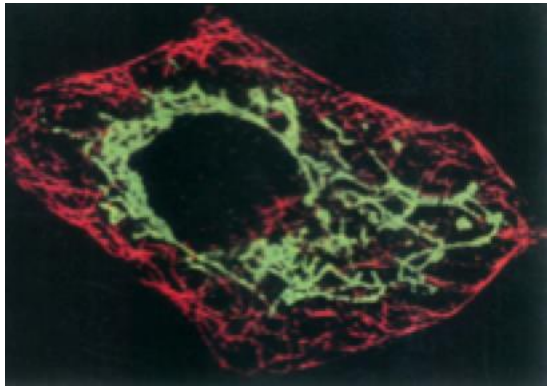

NETWORKS

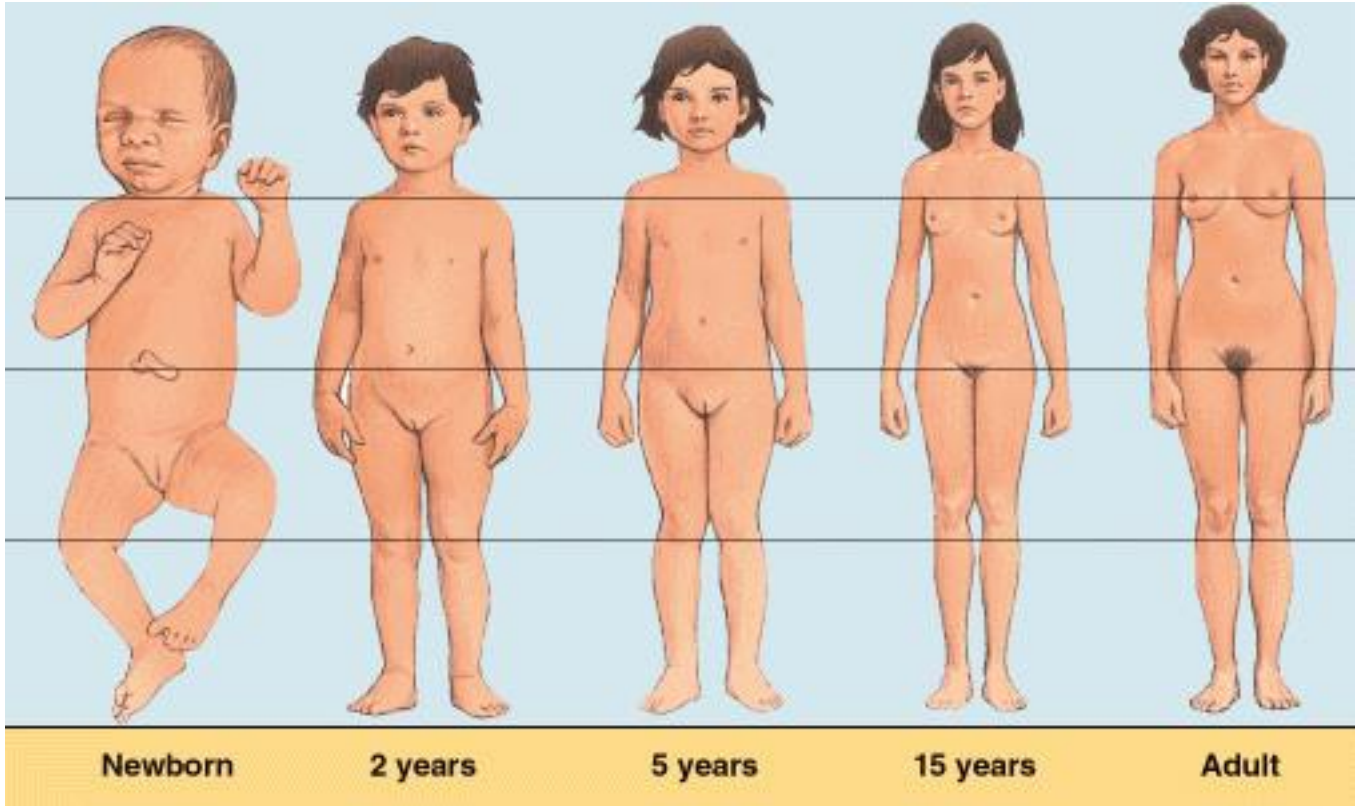



B








Newborn
2 years
5 years
15 years
Adult

Energy and human life

Chemical energy
- Carbohydrates
- Fats
- Others

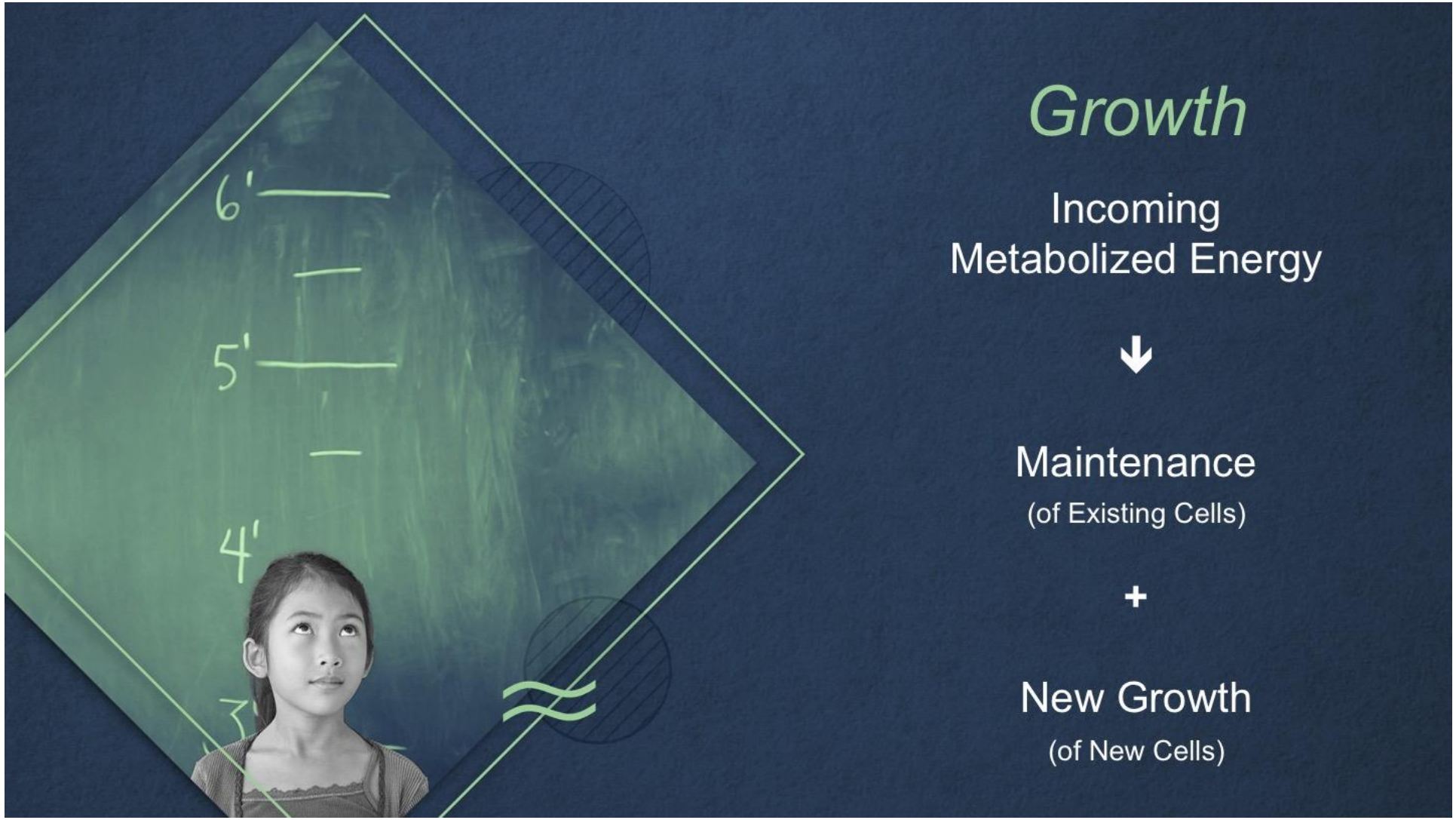
Chemical waste
- Carbon dioxide
- Water

Heat

ATP
- body's "energy currency"

metabolism

Heat



Growth

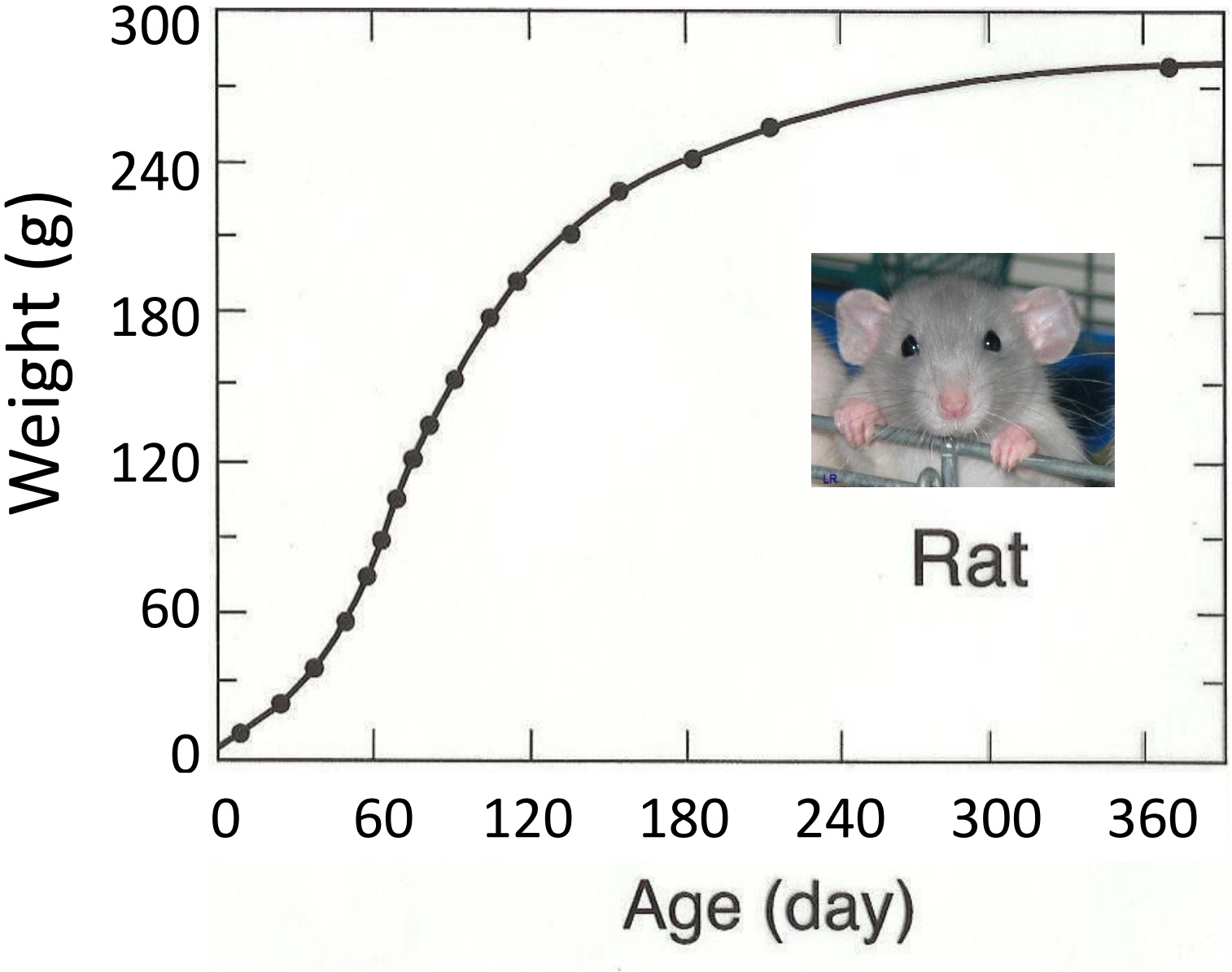
Incoming
Metabolized Energy

↓

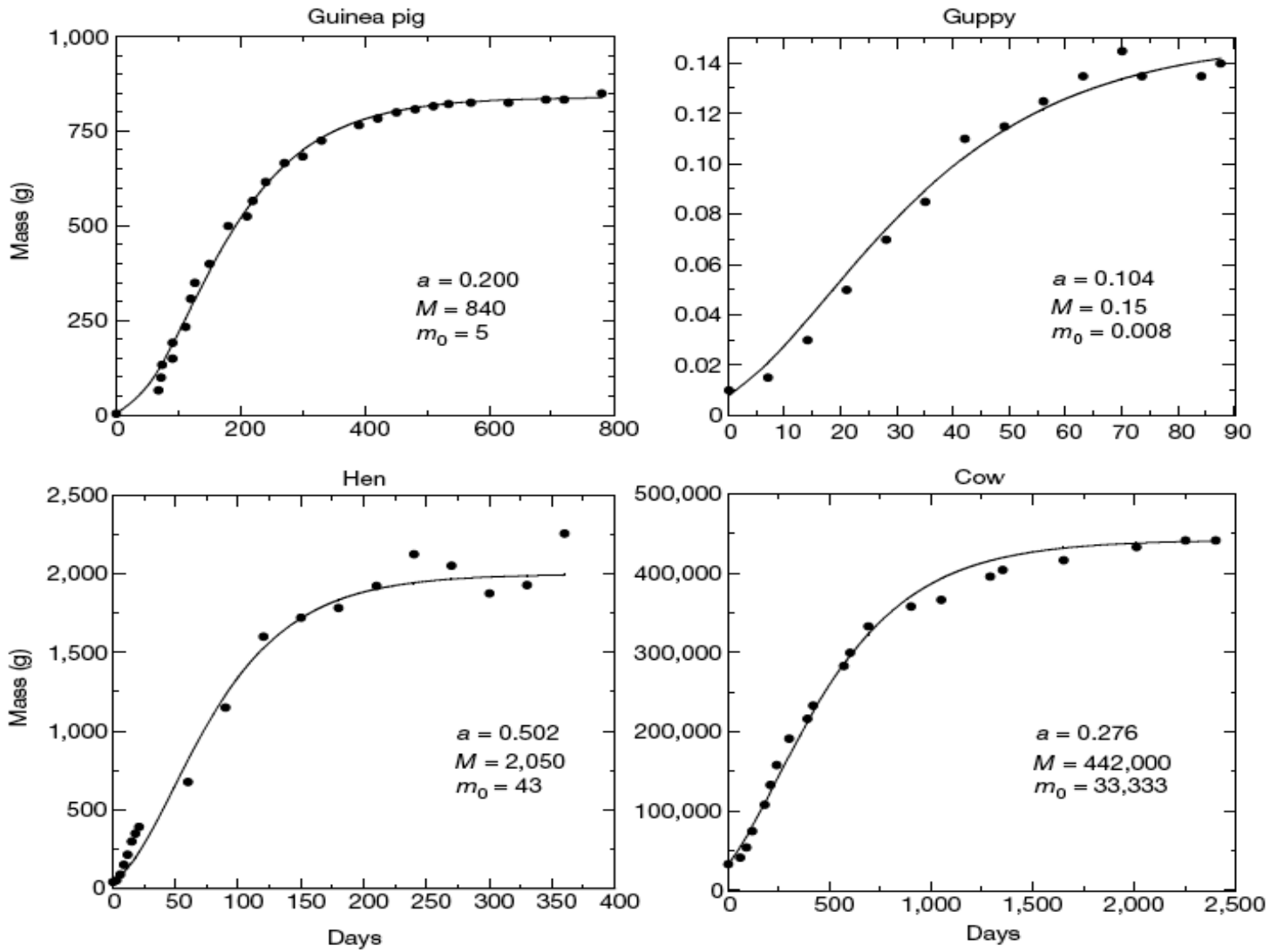
Maintenance
(of Existing Cells)

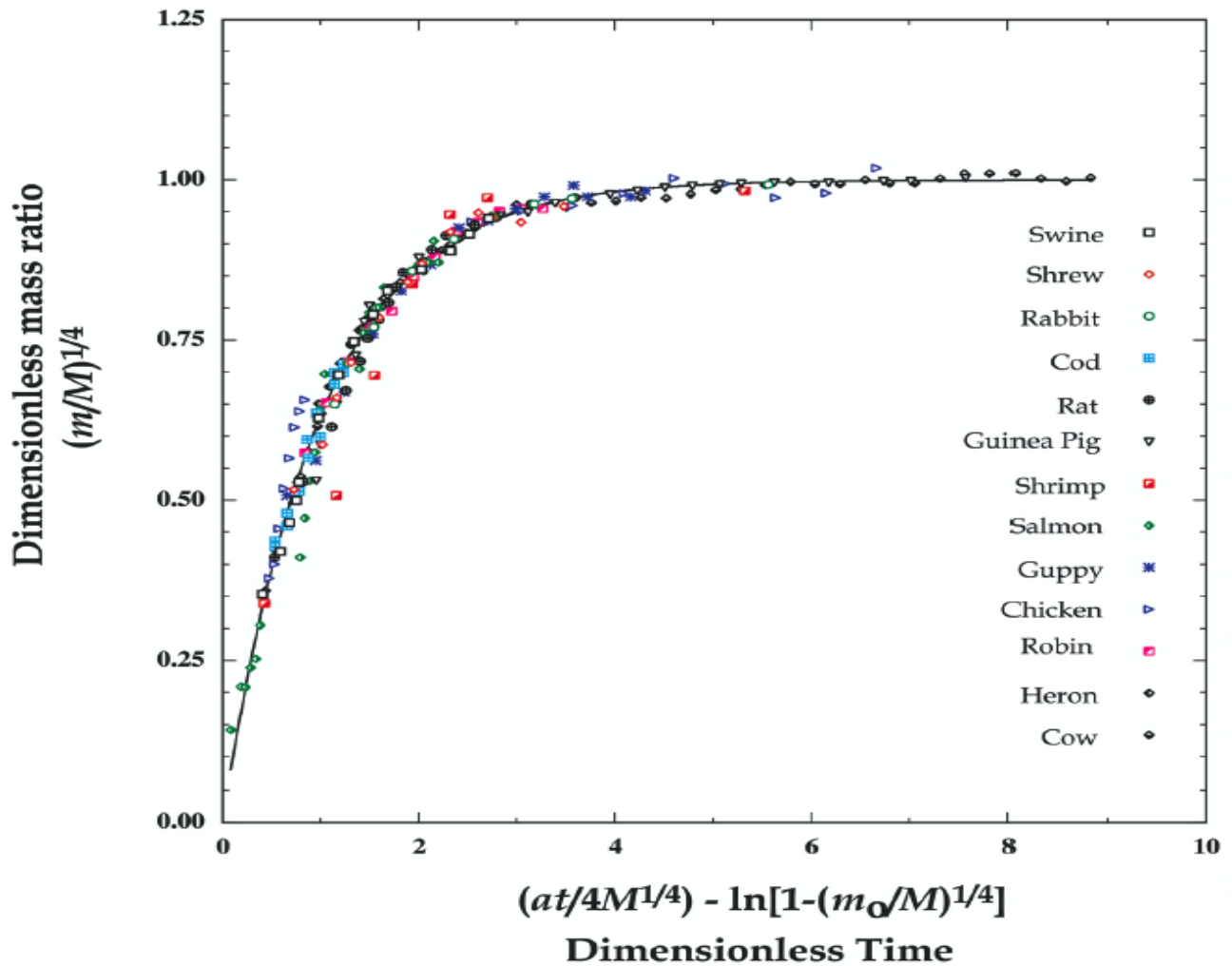
+

New Growth
(of New Cells)



SUB-LINEAR SCALING
LEADS TO BOUNDED GROWTH


Guinea pig
Mass (g)
1,000
750
500
250
0
0
200
400
600
800
a = 0.200
M = 840
m0 = 5
Guppy
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
60
70
80
90
a = 0.104
M = 0.15
m0 = 0.008
Hen
Mass (g)
2,500
2,000
1,500
1,000
500
0
0
50
100
150
200
250
300
350
400
Days
a = 0.502
M = 2,050
m0 = 43
Cow
500,000
400,000
300,000
200,000
100,000
0
0
500
1,000
1,500
2,000
2,500
Days
a = 0.276
M = 442,000
m0 = 33,333


Dimensionless mass ratio
$(m/M)^{1/4}$
1.25
1.00
0.75
0.50
0.25
0.00
0
2
4
6
8
10
$(at/4M^{1/4}) - \ln[1-(m_o/M)^{1/4}]$
Dimensionless Time
Swine
Shrew
Rabbit
Cod
Rat
Guinea Pig
Shrimp
Salmon
Guppy
Chicken
Robin
Heron
Cow

BIOLOGY (LIFE)

a) ***DOMINATED BY SYSTEMATIC, PREDICTABLE, NON-LINEAR (UNIVERSAL) SCALING LAWS***

b) ***ECONOMIES OF SCALE (THE BIGGER YOU ARE, THE LESS YOU NEED PER "CAPITA") - SUBLINEAR***

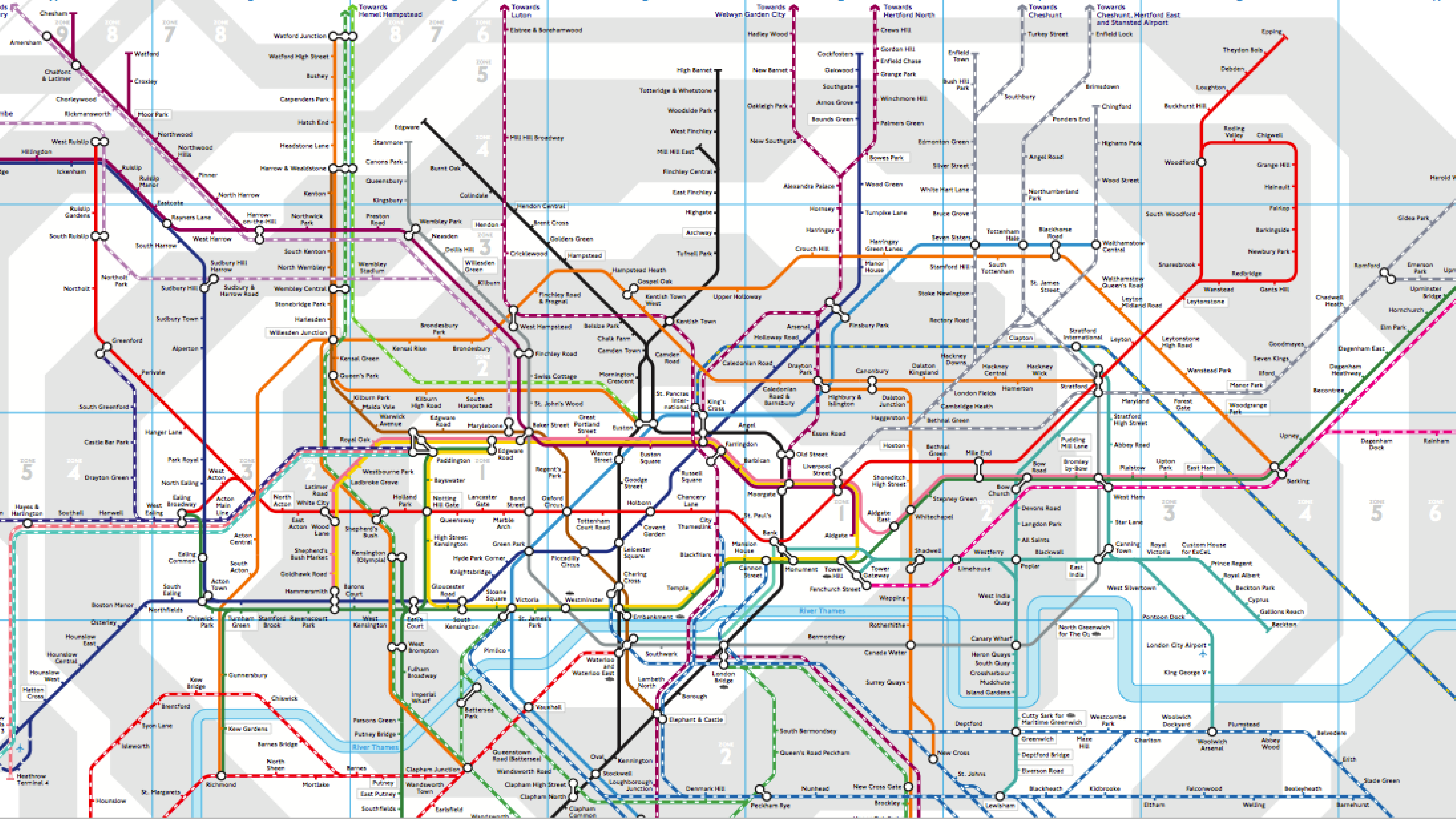
c) PACE OF LIFE SYSTEMATICALLY SLOWS WITH INCREASING SIZE

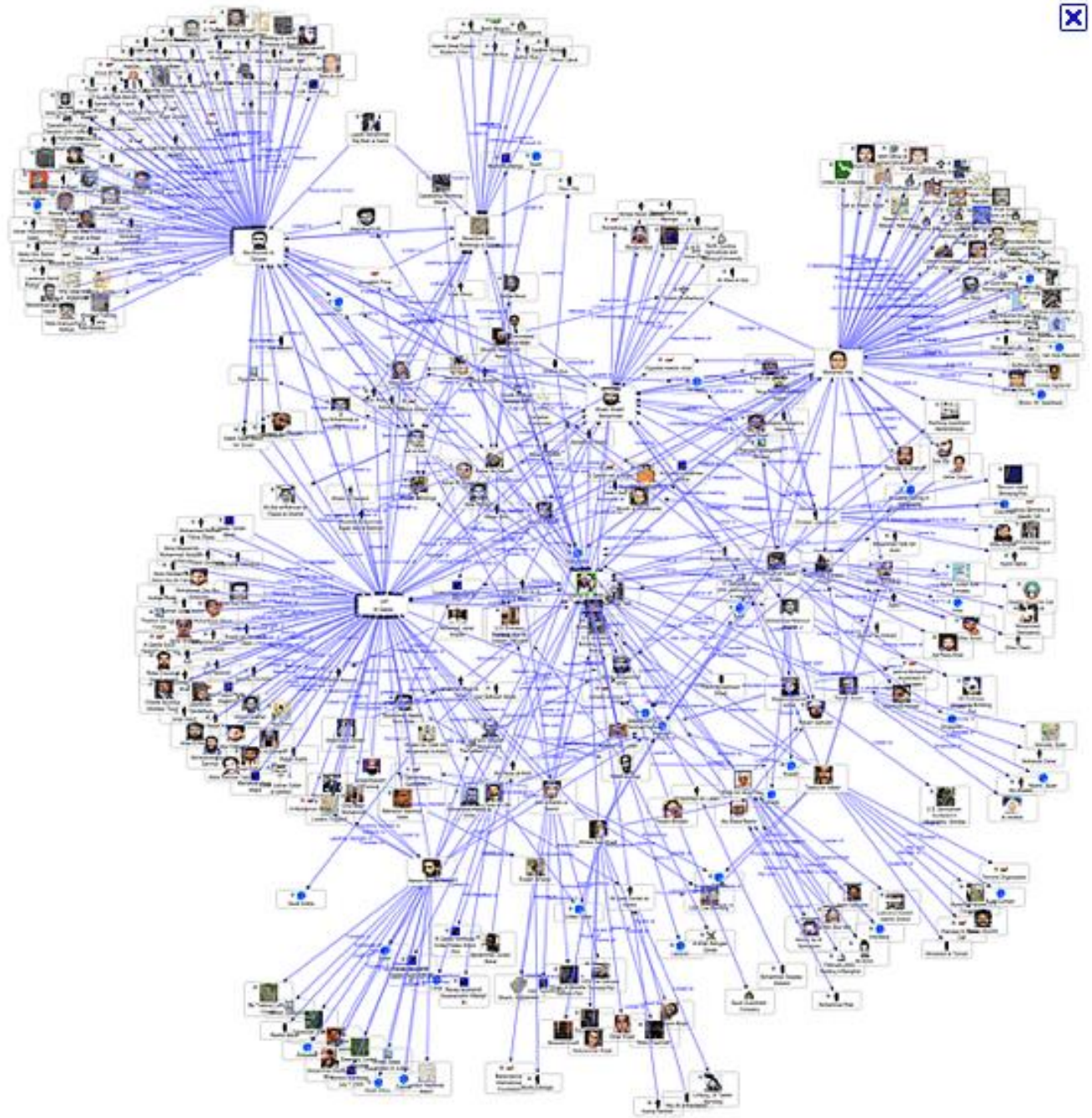
d) GROWTH IS SIGMOIDAL REACHING A STABLE SIZE AT MATURITY

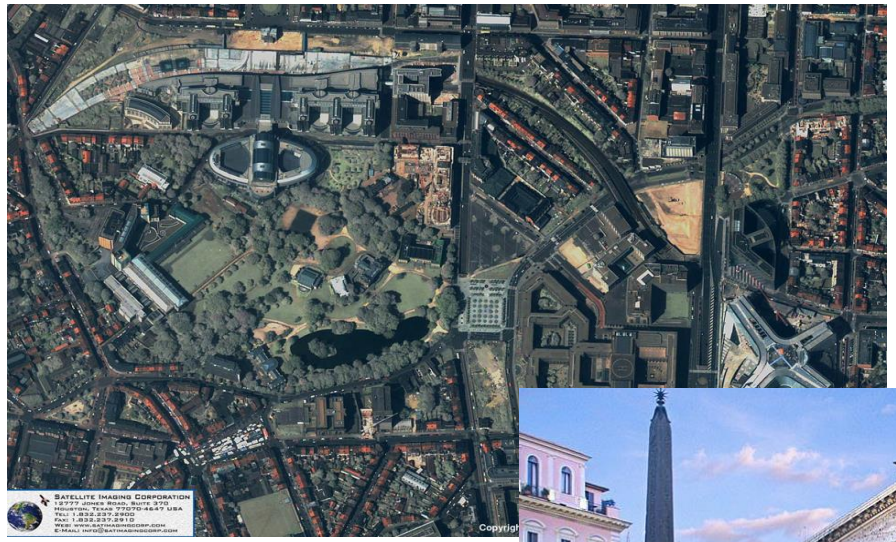
e) FINITE LIFESPAN

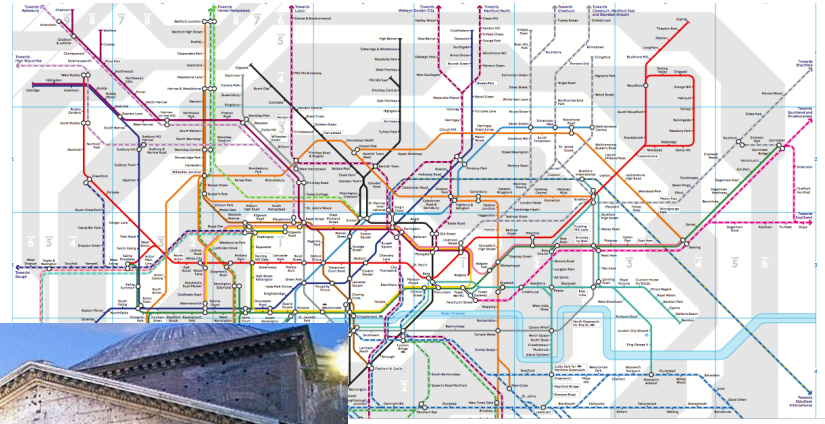
e) EXPLAINED BY DYNAMICS OF NETWORKS

SATELLITE IMAGING CORPORATION
12777 JONES ROAD, SUITE 370
HOUSTON, TEXAS 77070-4647 USA
TEL: 1.832.237.2900

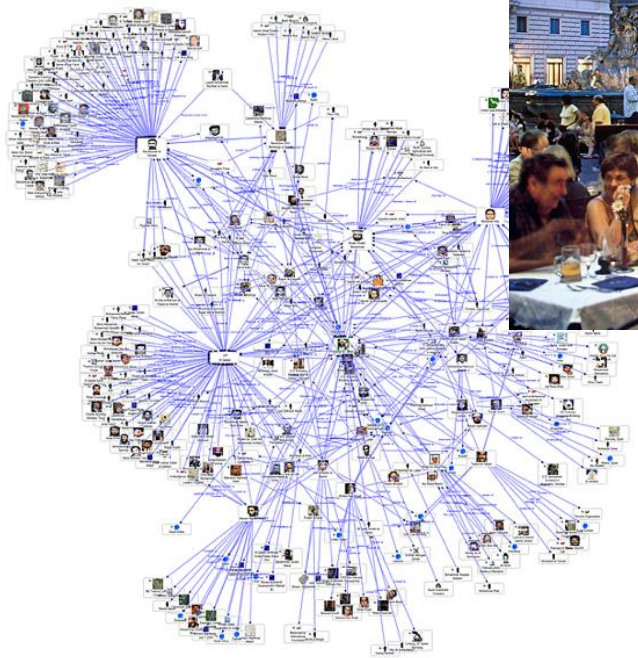

Chesham
Amersham
Chalfont & Latimer
Watford
Croxley
Chorleywood
Rickmansworth
Moor Park
Northwood
Northwood Hills
Pinner
North Harrow
West Ruislip
Hillingdon
Ickenham
Ruislip
Ruislip Manor
Eastcote
Rayners Lane
Ruislip Gardens
South Ruislip
South Harrow
West Harrow
Harrow-on-the-Hill
Northwick Park
Preston Road
Wembley Park
Sudbury Hill Harrow
Sudbury Hill
Sudbury & Harrow Road
Northolt Park
Northolt
Sudbury Town
Alperton
Greenford
Perivale
South Greenford
Hanger Lane
Castle Bar Park
Drayton Green
Towards Hemel Hempstead
Watford Junction
Watford High Street
Bushey
Carpenders Park
Hatch End
Headstone Lane
Harrow & Wealdstone
Kenton
South Kenton
North Wembley
Wembley Central
Wembley Stadium
Stonebridge Park
Harlesden
Willesden Junction
Kensal Green
Queen's Park
Kensal Rise
Brondesbury Park
Brondesbury
Kilburn Park
Maida Vale
Kilburn High Road
South Hampstead
Warwick Avenue
Edgware Road
Marylebone
Royal Oak
Edgware
Stanmore
Canons Park
Queensbury
Kingsbury
Burnt Oak
Colindale
Neasden
Dollis Hill
Willesden Green
Kilburn
Hendon
Towards Luton
Elstree & Borehamwood
Mill Hill Broadway
Hendon Central
Brent Cross
Golders Green
Hampstead
Cricklewood
Towards Welwyn Garden City
Hadley Wood
New Barnet
Oakleigh Park
New Southgate
High Barnet
Totteridge & Whetstone
Woodside Park
West Finchley
Mill Hill East
Finchley Central
East Finchley
Highgate
Archway
Tufnell Park
Cockfosters
Oakwood
Southgate
Arnos Grove
Bounds Green
Wood Green
Turnpike Lane
Manor House
Towards Hertford North
Crews Hill
Gordon Hill
Enfield Chase
Grange Park
Winchmore Hill
Palmers Green
Bowes Park
Alexandra Palace
Hornsey
Harringay
Crouch Hill
Harringay Green Lanes
Hampstead Heath
Gospel Oak
Kentish Town West
Upper Holloway
Finchley Road & Frognal
West Hampstead
Belsize Park
Kentish Town
Chalk Farm
Camden Town
Camden Road
Finchley Road
Swiss Cottage
St. John's Wood
Mornington Crescent
Arsenal
Holloway Road
Finsbury Park
Caledonian Road
Drayton Park
Caledonian Road & Barnsbury
Highbury & Islington
Canonbury
Dalston Kingsland
Dalston Junction
Haggerston
Hoxton
St. Pancras International
King's Cross
Euston
Baker Street
Great Portland Street
Angel
Essex Road
Farringdon
Enfield Town
Bush Hill Park
Edmonton Green
Silver Street
White Hart Lane
Bruce Grove
Seven Sisters
Stamford Hill
Stoke Newington
Rectory Road
Hackney Downs
London Fields
Cambridge Heath
Bethnal Green
Towards Cheshunt
Turkey Street
Towards Cheshunt, Hertford East and Stansted Airport
Enfield Lock
Southbury
Brimsdown
Ponders End
Chingford
Angel Road
Highams Park
Wood Street
Northumberland Park
Tottenham Hale
Blackhorse Road
Walthamstow Central
South Tottenham
St. James Street
Walthamstow Queen's Road
Leyton Midland Road
Clapton
Stratford International
Leyton
Leytonstone High Road
Hackney Central
Hackney Wick
Homerton
Stratford
Maryland
Forest Gate
Wanstead Park
Manor Park
Woodgrange Park
Stratford High Street
Pudding Mill Lane
Abbey Road
Epping
Theydon Bois
Debden
Loughton
Buckhurst Hill
Roding Valley
Chigwell
Woodford
Grange Hill
Hainault
Fairlop
Barkingside
Newbury Park
South Woodford
Snaresbrook
Redbridge
Wanstead
Gants Hill
Leytonstone
Harold Wood
Gidea Park
Romford
Emerson Park
Upminster Bridge
Chadwell Heath
Hornchurch
Elm Park
Goodmayes
Seven Kings
Ilford
Dagenham East
Dagenham Heathway
Becontree
Upney
Dagenham Dock
Rainham
Hayes & Harlington
Southall
Hanwell
West Ealing
Ealing Broadway
Park Royal
North Ealing
West Acton
Acton Main Line
North Acton
East Acton
White City
Wood Lane
Latimer Road
Ladbroke Grove
Westbourne Park
Paddington
Bayswater
Notting Hill Gate
Lancaster Gate
Holland Park
Shepherd's Bush
Shepherd's Bush Market
Kensington (Olympia)
Goldhawk Road
Hammersmith
Barons Court
Queensway
Marble Arch
High Street Kensington
Green Park
Hyde Park Corner
Knightsbridge
Gloucester Road
Sloane Square
Acton Central
South Acton
Ealing Common
Acton Town
South Ealing
Boston Manor
Northfields
Osterley
Chiswick Park
Turnham Green
Stamford Brook
Ravenscourt Park
West Kensington
Earl's Court
South Kensington
Hounslow East
Hounslow Central
Hounslow West
Hatton Cross
Heathrow Terminal 4
Gunnersbury
Kew Bridge
Brentford
Chiswick
Syon Lane
Isleworth
Kew Gardens
Barnes Bridge
North Sheen
Barnes
Mortlake
Richmond
St. Margarets
Hounslow
West Brompton
Fulham Broadway
Imperial Wharf
Parsons Green
Putney Bridge
River Thames
Battersea Park
Pimlico
Clapham Junction
Putney
East Putney
Wandsworth Town
Southfields
Earlsfield
Regent's Park
Bond Street
Oxford Circus
Warren Street
Euston Square
Goodge Street
Tottenham Court Road
Holborn
Russell Square
Chancery Lane
Barbican
Moorgate
Old Street
Liverpool Street
Piccadilly Circus
Leicester Square
Covent Garden
City Thameslink
St. Paul's
Bank
Mansion House
Blackfriars
Charing Cross
Temple
Westminster
Victoria
St. James's Park
Embankment
Cannon Street
Monument
Tower Hill
Tower Gateway
Fenchurch Street
Aldgate
Aldgate East
Shoreditch High Street
Whitechapel
Stepney Green
Mile End
Shadwell
Wapping
Limehouse
Rotherhithe
Bermondsey
Canada Water
Southwark
Waterloo and Waterloo East
Lambeth North
London Bridge
Borough
Vauxhall
Elephant & Castle
South Bermondsey
Queen's Road Peckham
Surrey Quays
Deptford
New Cross
St. Johns
New Cross Gate
Brockley
Oval
Kennington
Stockwell
Loughborough Junction
Denmark Hill
Nunhead
Peckham Rye
Queenstown Road (Battersea)
Wandsworth Road
Clapham High Street
Clapham North
Clapham Common
Lewisham
Bow Road
Bow Church
Bromley-by-Bow
Plaistow
Upton Park
East Ham
Barking
West Ham
Devons Road
Langdon Park
All Saints
Westferry
Poplar
Blackwall
East India
Star Lane
Canning Town
Royal Victoria
Custom House for ExCeL
Prince Regent
Royal Albert
Beckton Park
Cyprus
Gallions Reach
Beckton
West Silvertown
Pontoon Dock
London City Airport
King George V
West India Quay
Canary Wharf
Heron Quays
South Quay
Crossharbour
Mudchute
Island Gardens
North Greenwich for The O2
Cutty Sark for Maritime Greenwich
Greenwich
Deptford Bridge
Elverson Road
Westcombe Park
Maze Hill
Charlton
Woolwich Dockyard
Woolwich Arsenal
Plumstead
Abbey Wood
Belvedere
Erith
Slade Green
Blackheath
Kidbrooke
Eltham
Falconwood
Welling
Bexleyheath
Barnehurst

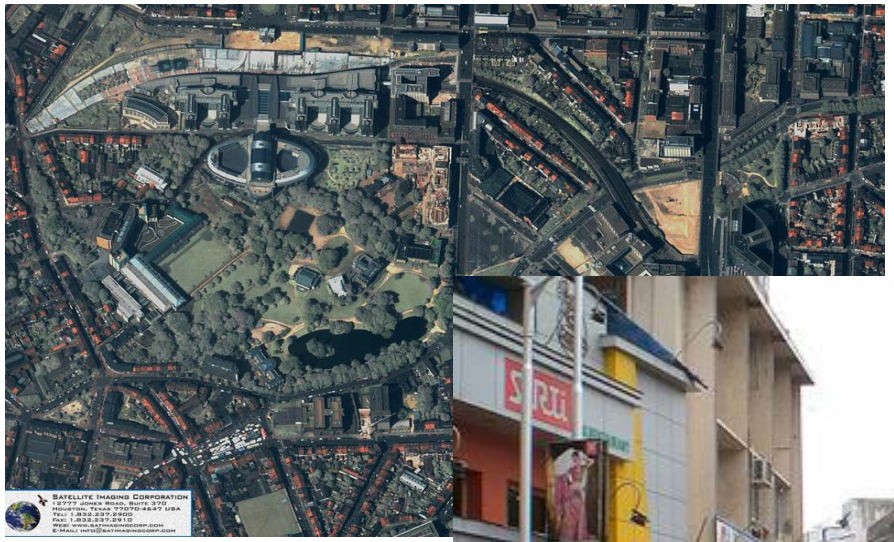


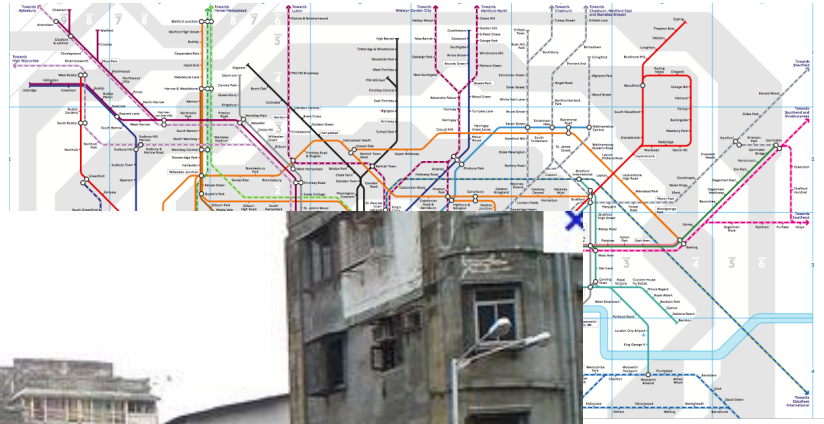

Satellite Imaging Corporation
12777 Jones Road, Suite 370
Houston, Texas 77070-4647 USA
Tel: 1.832.237.2900
Fax: 1.832.237.2909
Web: www.satimagingcorp.com
E-Mail: info@satimagingcorp.com

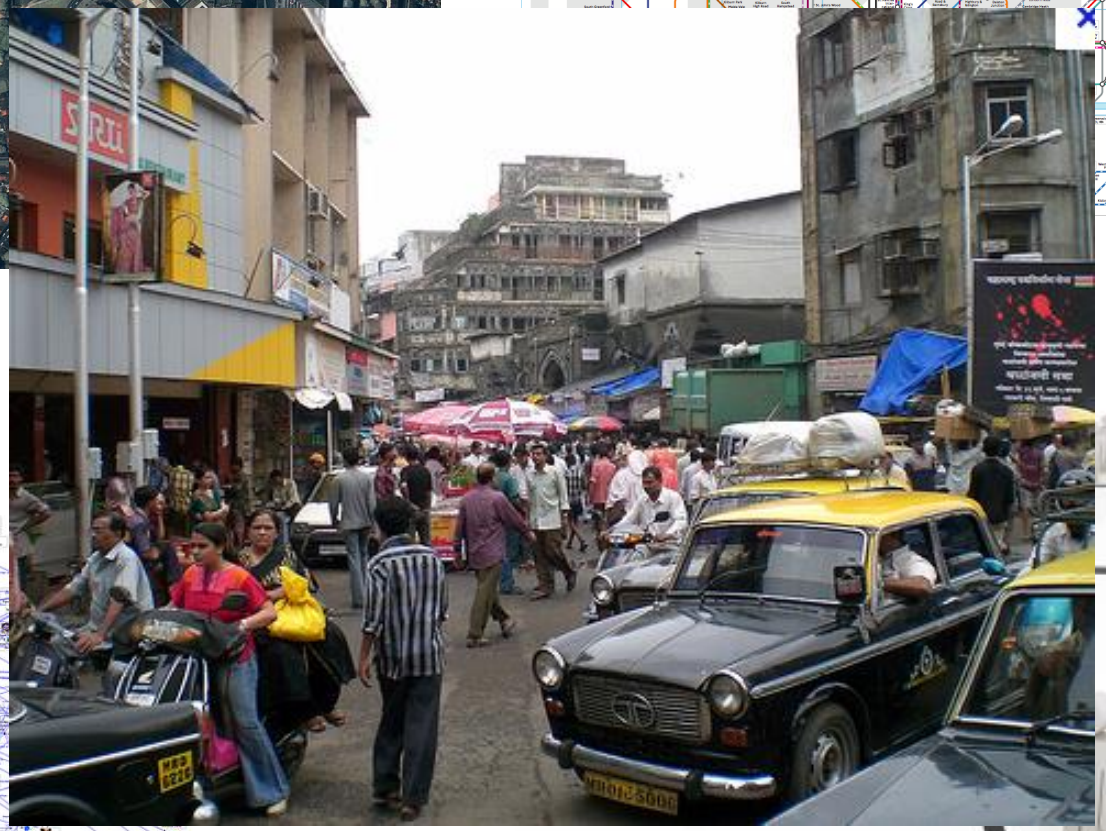


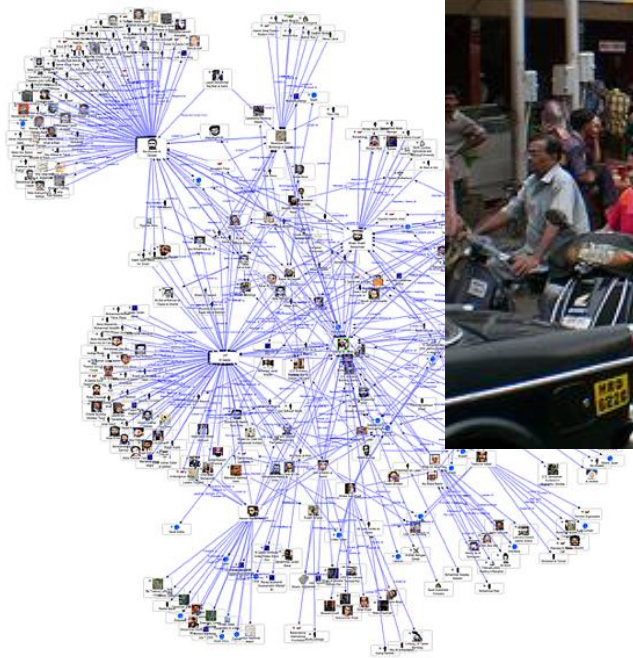

M·AGRIPPA·L·F·COS·TERTIVM·FECIT



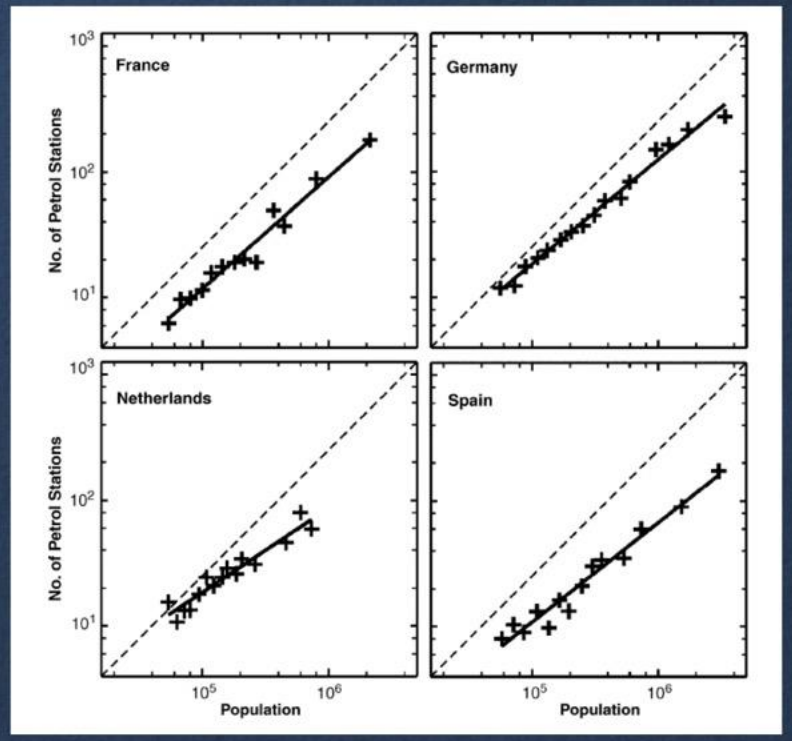

SATELLITE IMAGING CORPORATION
12777 JONES ROAD, SUITE 370
HOUSTON, TEXAS 77070-4647 USA
TEL: 1.832.237.2900
FAX: 1.832.237.2901
WEB: WWW.SATIMAGINGCORP.COM
E-MAIL: INFO@SATIMAGINGCORP.COM







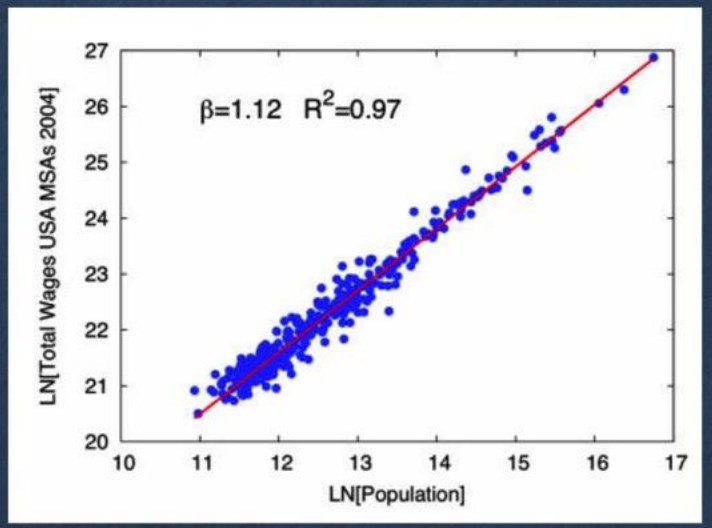
INFRASTRUCTURE



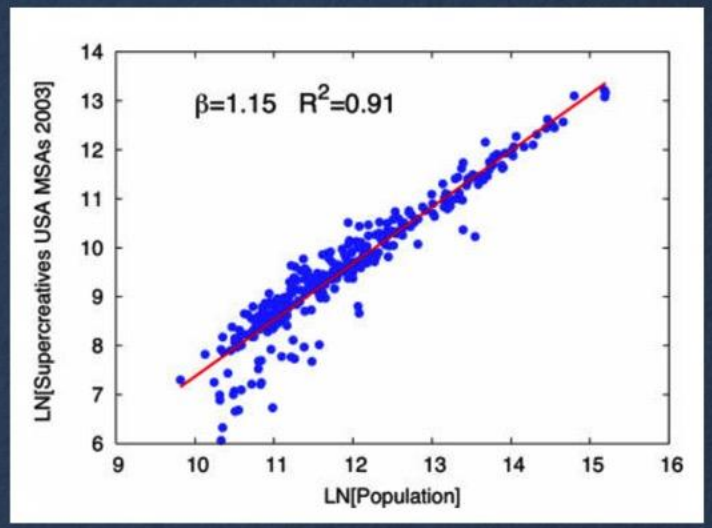
SUB-LINEAR SCALING

ECONOMY OF SCALE

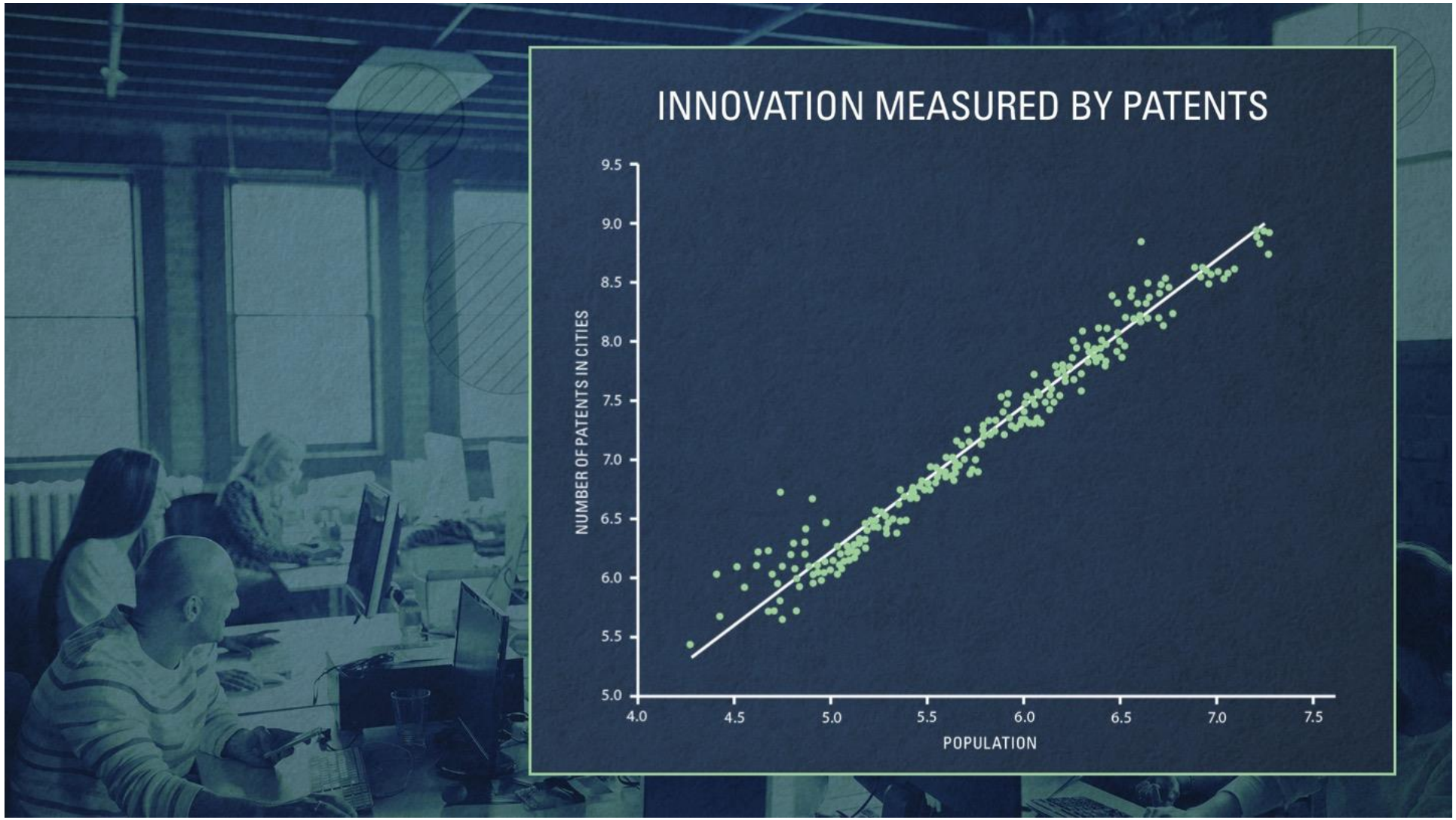
SUPER-LINEAR SCALING

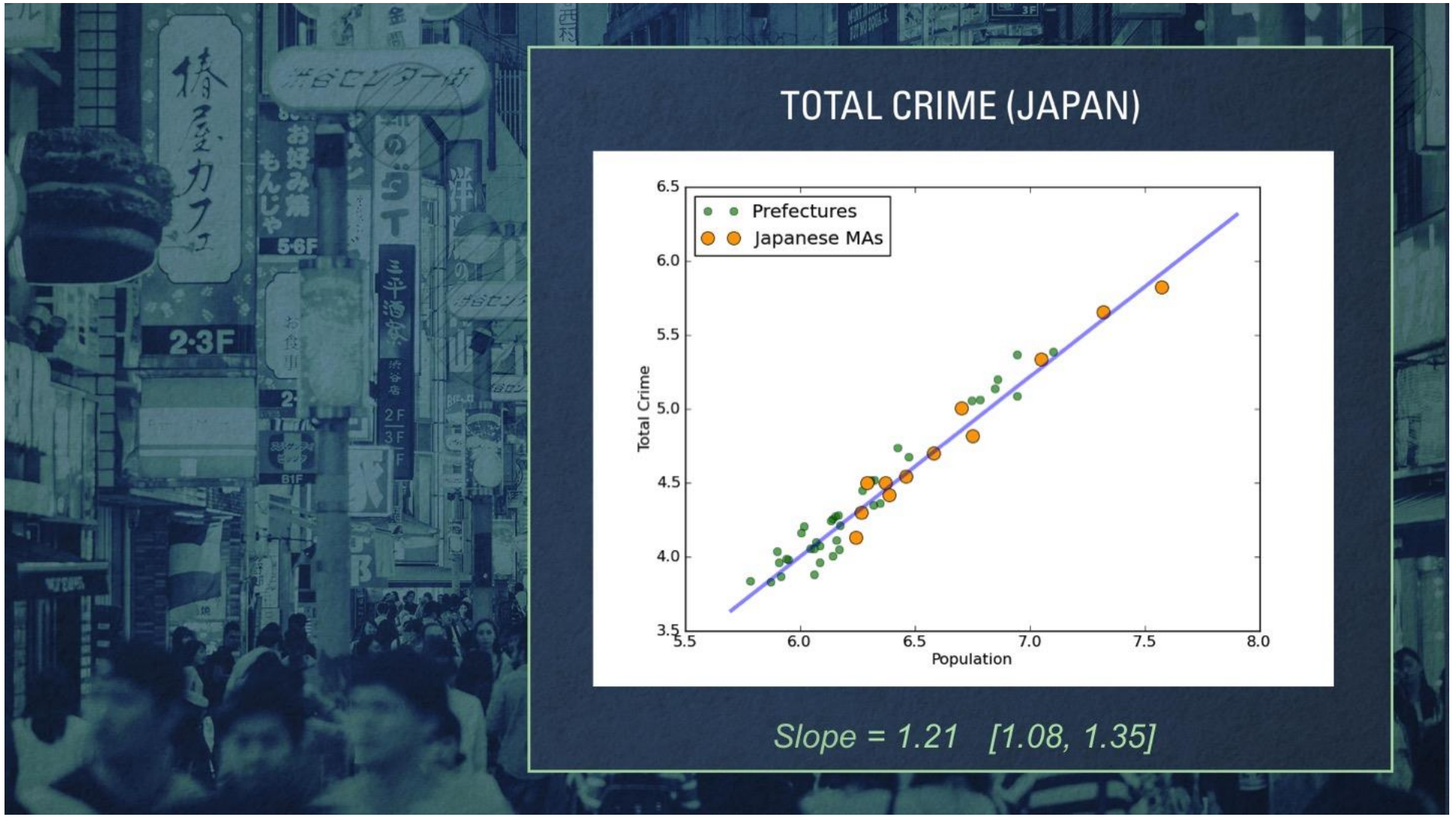


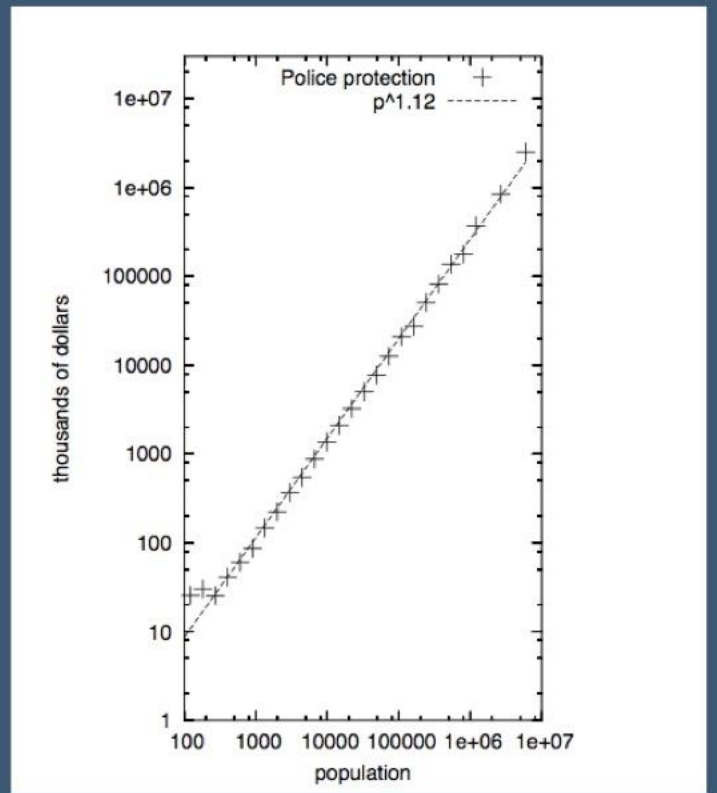
Total wages per MSA in 2004 for the USA vs. metropolitan population.

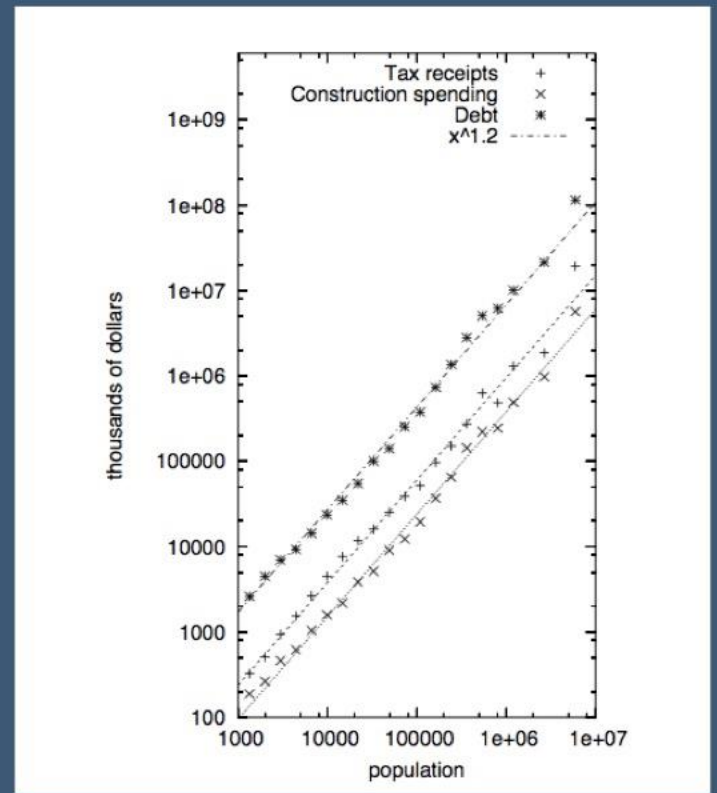


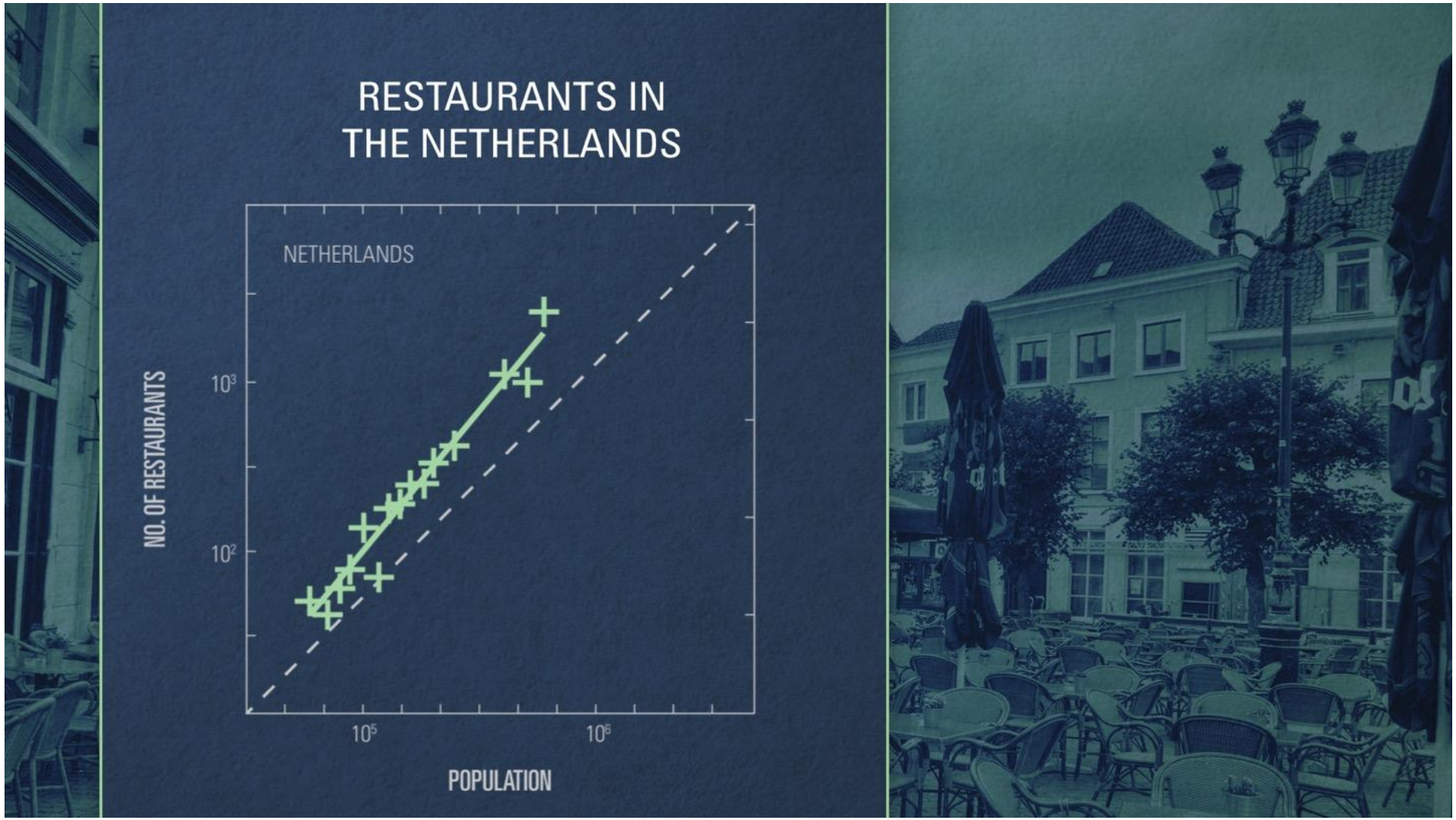
Supercreative employment per MSA in 2003, for the USA vs. metropolitan population.


INNOVATION MEASURED BY PATENTS
NUMBER OF PATENTS IN CITIES
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
POPULATION

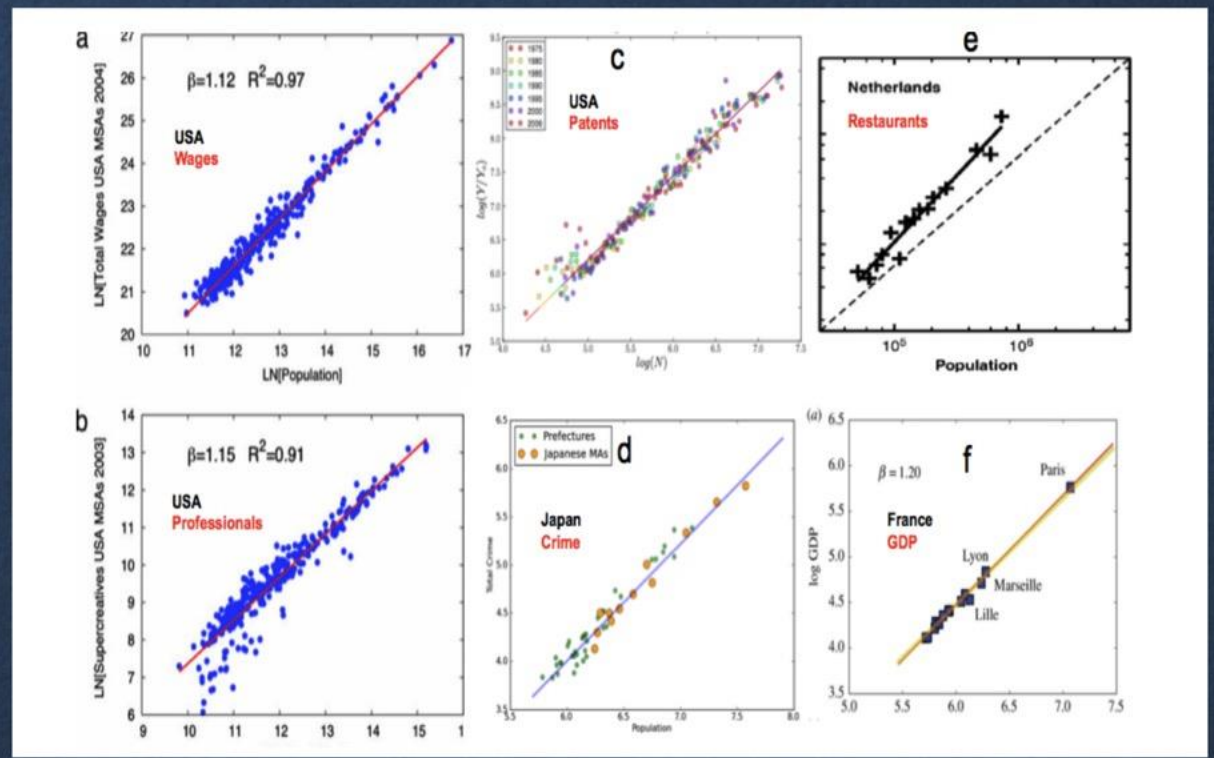

TOTAL CRIME (JAPAN)
Prefectures
Japanese MAs
Total Crime
Population
6.5
6.0
5.5
5.0
4.5
4.0
3.5
5.5
6.0
6.5
7.0
7.5
8.0
Slope = 1.21 [1.08, 1.35]


Police protection
p^1.12
thousands of dollars
population
1e+07
1e+06
100000
10000
1000
100
10
1
100
1000
10000
100000
1e+06
1e+07


Tax receipts
Construction spending
Debt
x^1.2
thousands of dollars
population
1e+09
1e+08
1e+07
1e+06
100000
10000
1000
100
1000
10000
100000
1e+06
1e+07


RESTAURANTS IN
THE NETHERLANDS
NETHERLANDS
NO. OF RESTAURANTS
10^3
10^2
10^5
10^6
POPULATION

UNIVERSALITY OF URBAN SCALING




THE GOOD,
THE BAD,
THE UGLY

ON AVERAGE DOUBLING THE SIZE OF A CITY SYSTEMATICALLY INCREASES

ON AVERAGE DOUBLING THE SIZE OF A CITY

SYSTEMATICALLY INCREASES

INCOME, WEALTH, PATENTS, COLLEGES, CREATIVE PEOPLE, POLICE, AIDS & FLU, CRIME, SOCIAL INTERACTIONS,……

ON AVERAGE DOUBLING THE SIZE OF A CITY

SYSTEMATICALLY INCREASES

INCOME, WEALTH, PATENTS, COLLEGES, CREATIVE PEOPLE, POLICE, AIDS & FLU, CRIME, SOCIAL INTERACTIONS,……

ALL BY APPROXIMATELY 15%

REGARDLESS OF CITY

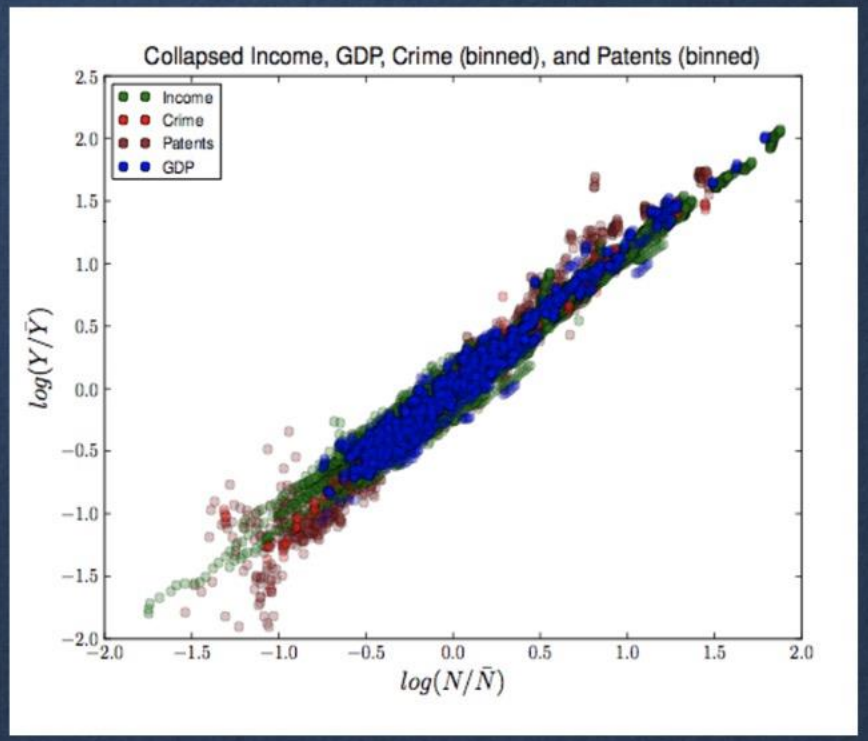
AND ……………

AND**.....**

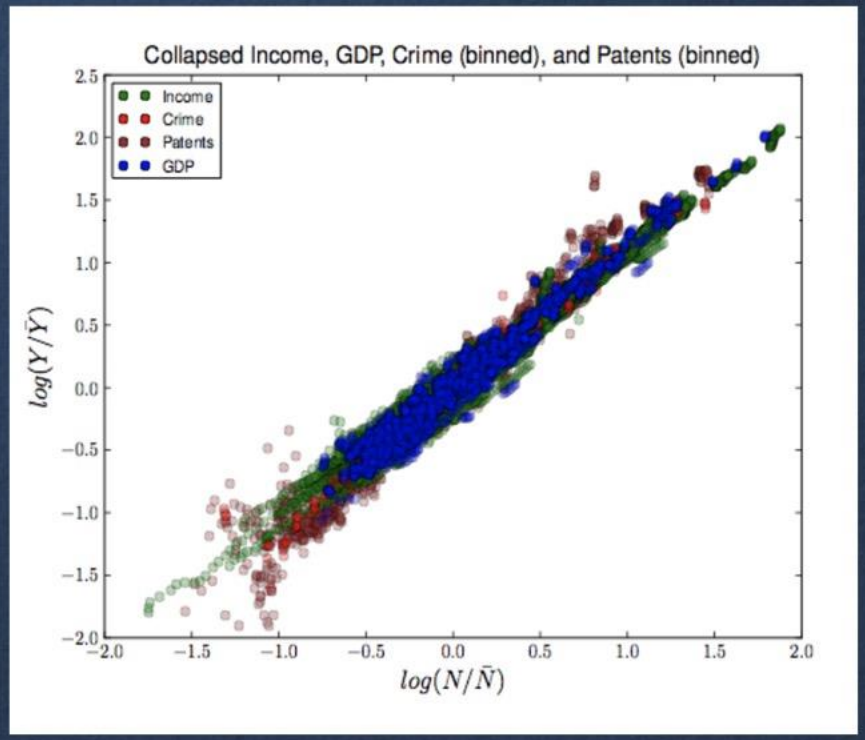
SAVES APPROXIMATELY 15% ON ALL INFRASTRUCTURE (ROADS, ELECTRICAL LINES, GAS STATIONS,.....)

Universality of Social Networks
(clustering hierarchies)

UNIVERSALITY

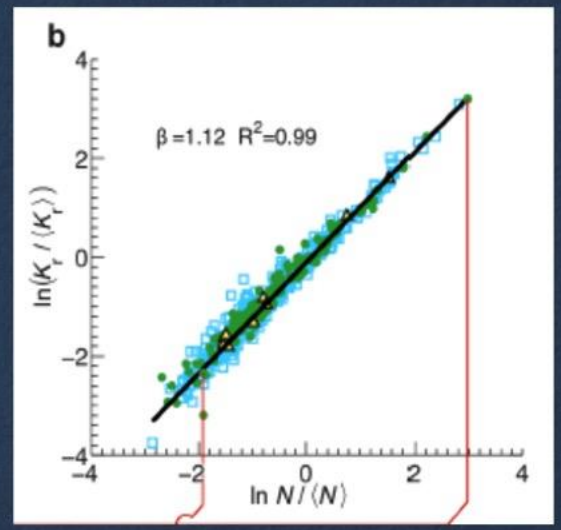


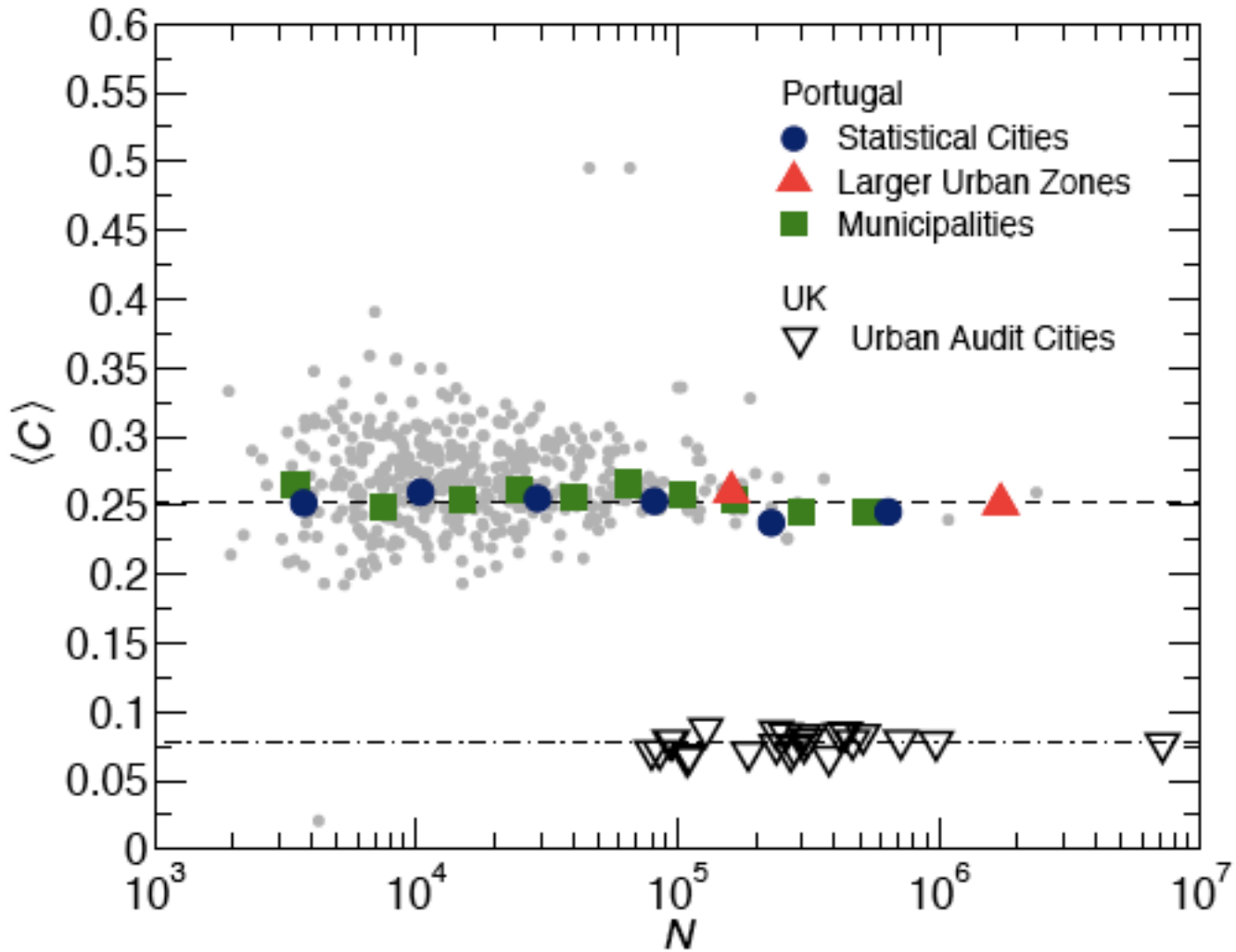
UNIVERSALITY



SOCIAL CONNECTIVITY

(Cell Phone Data)



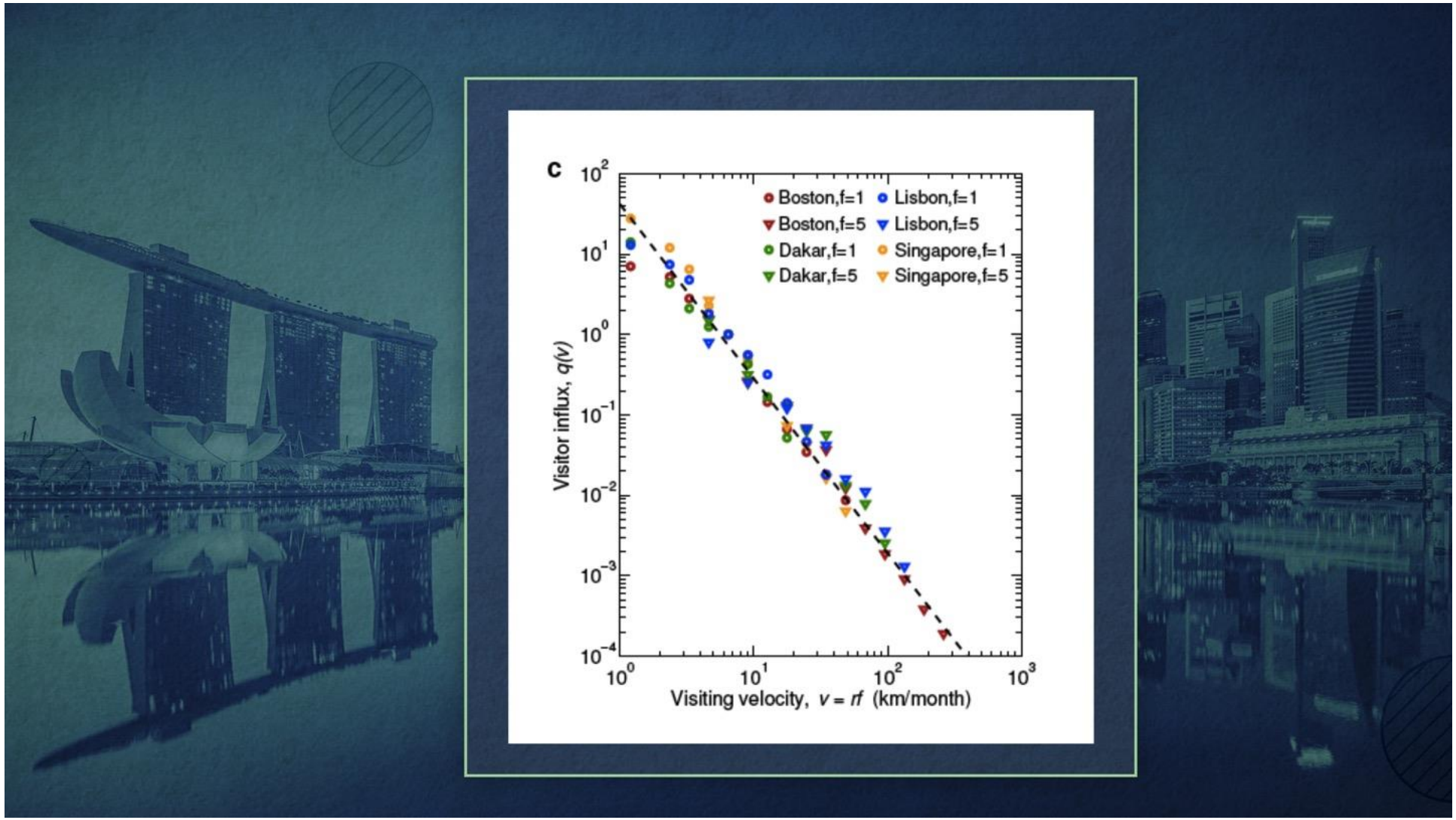

0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
⟨C⟩
Portugal
Statistical Cities
Larger Urban Zones
Municipalities
UK
Urban Audit Cities
10^3
10^4
10^5
10^6
10^7
N

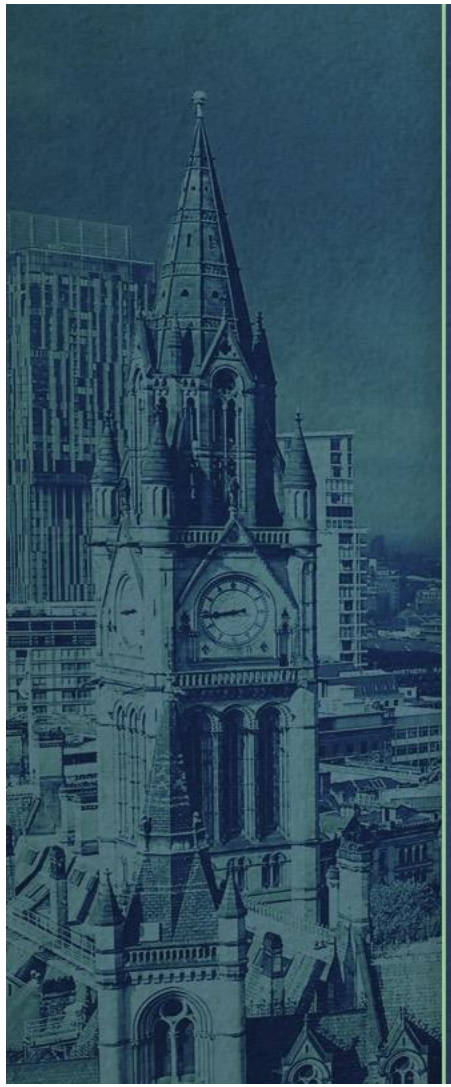
MOVEMENT IN CITIES

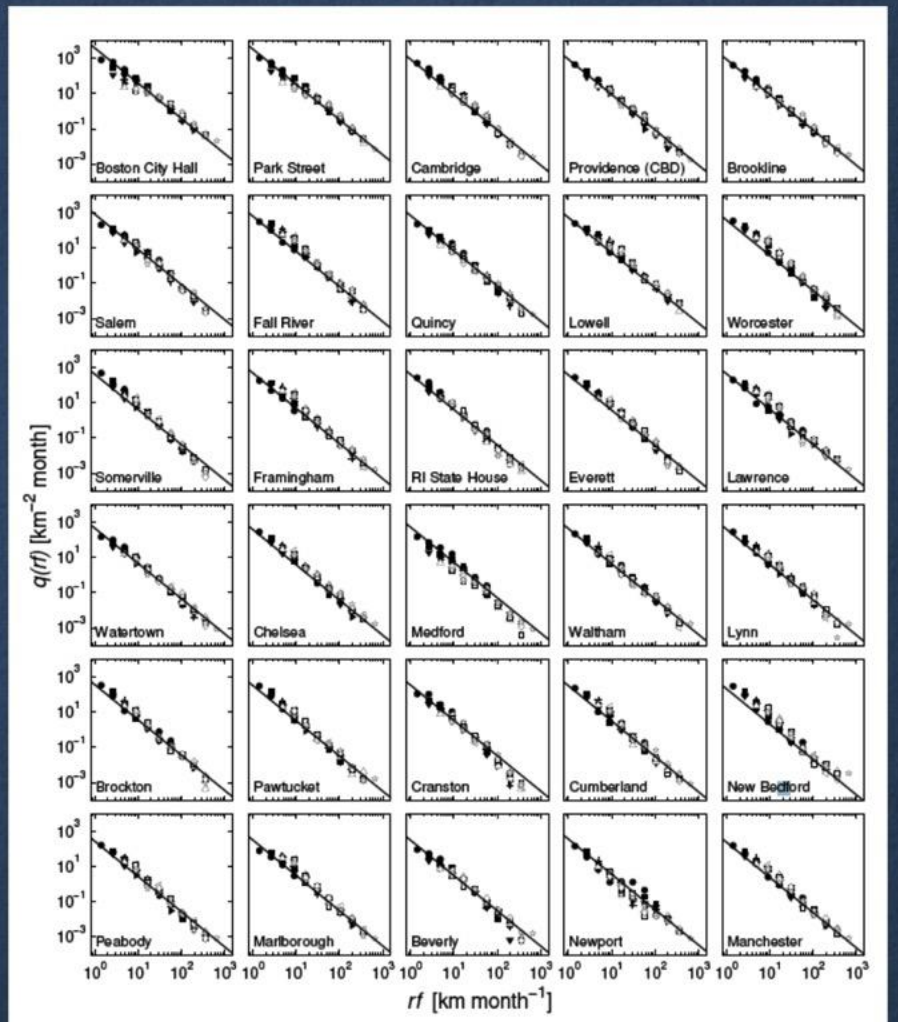
People on average minimize travel time and distance.

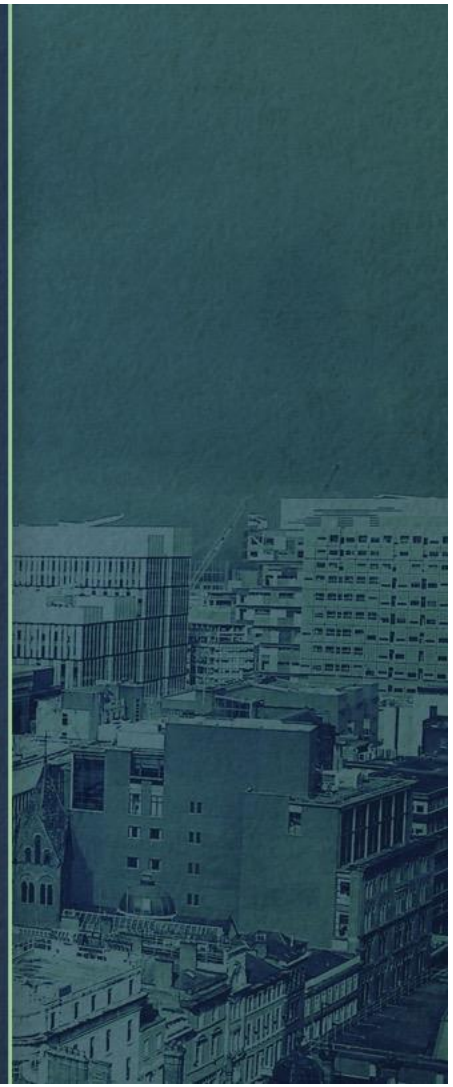
"Theorem": the number traveling to any location in any city from a distance r away f times a month is:

$$q(r,f) = \frac{A}{(rf)^2}$$


c
Boston,f=1
Lisbon,f=1
Boston,f=5
Lisbon,f=5
Dakar,f=1
Singapore,f=1
Dakar,f=5
Singapore,f=5
Visitor influx, q(v)
Visiting velocity, v = rf (km/month)



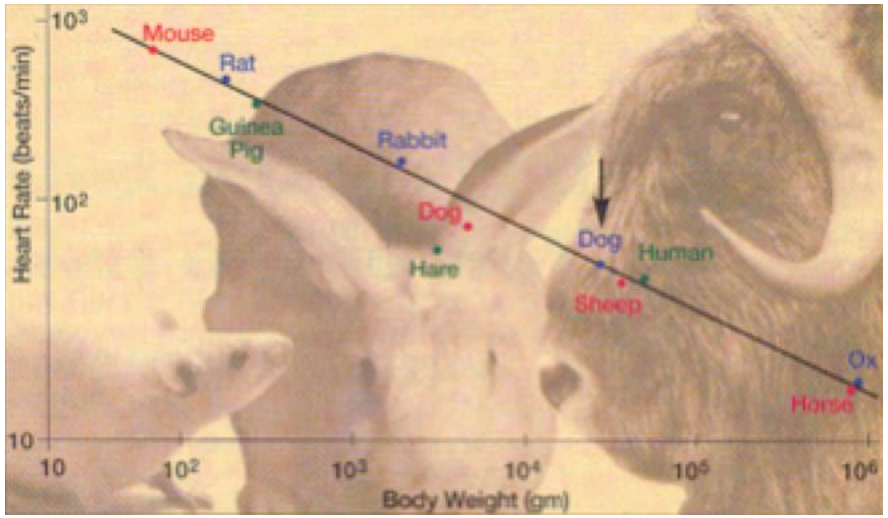

Boston City Hall
Park Street
Cambridge
Providence (CBD)
Brookline
Salem
Fall River
Quincy
Lowell
Worcester
Somerville
Framingham
RI State House
Everett
Lawrence
Watertown
Chelsea
Medford
Waltham
Lynn
Brockton
Pawtucket
Cranston
Cumberland
New Bedford
Peabody
Marlborough
Beverly
Newport
Manchester
$q(rf)$ [km^{-2} month]
rf [km month^{-1}]

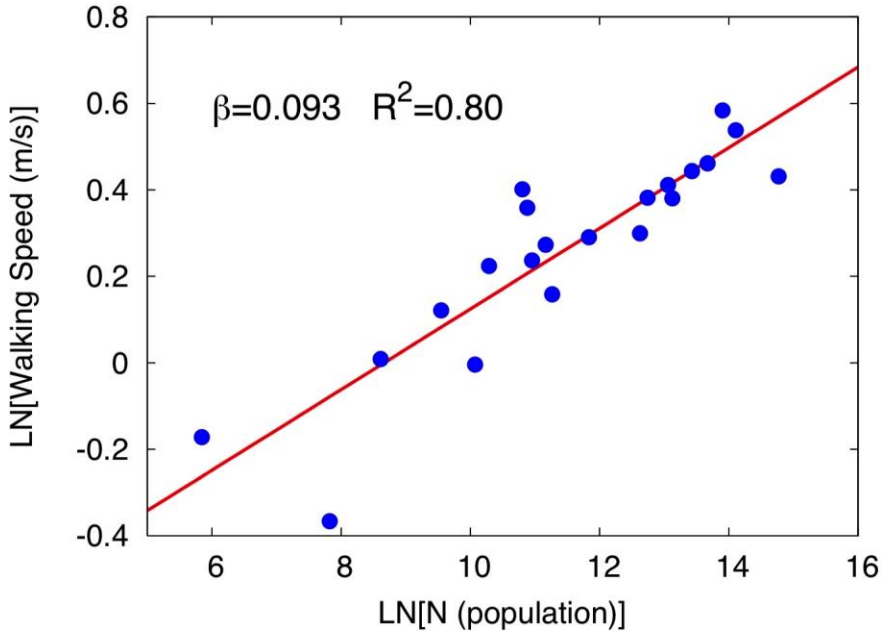



Jurong West
Tampines
City Hall
Bugis
Toa Payoh
1.34,103.71
1.36,103.94
1.29,103.85
1.30,103.85
1.33,103.85
1.30,103.83
1.43,103.83
1.44,103.79
1.30,103.84
1.39,103.90
1.37,103.89
1.28,103.84
1.36,103.95
1.31,103.85
1.31,103.86
1.33,103.93
1.32,103.93
1.37,103.85
1.34,103.70
1.35,103.94
1.35,103.72
1.35,103.75
1.44,103.80
1.37,103.85
1.28,103.83
Raffles Place
1.28,103.85
1.35,103.95
1.44,103.78
1.37,103.95
1.31,103.89
$q(rf)$ [km^{-2} month]
rf [km month^{-1}]

NETWORK DYNAMICS DETERMINES THE PACE OF LIFE

IF THE SLOPE IS < 1 (SUBLINEAR)	*PACE OF LIFE SLOWS DOWN*
IF THE SLOPE IS > 1 (SUPERLINEAR)	*PACE OF LIFE SPEEDS UP*


Heart Rate (beats/min)
10^3
10^2
10
Mouse
Rat
Guinea Pig
Rabbit
Dog
Hare
Dog
Human
Sheep
Ox
Horse
10
10^2
10^3
10^4
10^5
10^6
Body Weight (gm)


β=0.093 R^2=0.80
LN[Walking Speed (m/s)]
0.8
0.6
0.4
0.2
0
-0.2
-0.4
6
8
10
12
14
16
LN[N (population)]

Research revealed almost half the nation found the slow pace of high streets to be their biggest shopping bugbear. Photo: Mercury Press

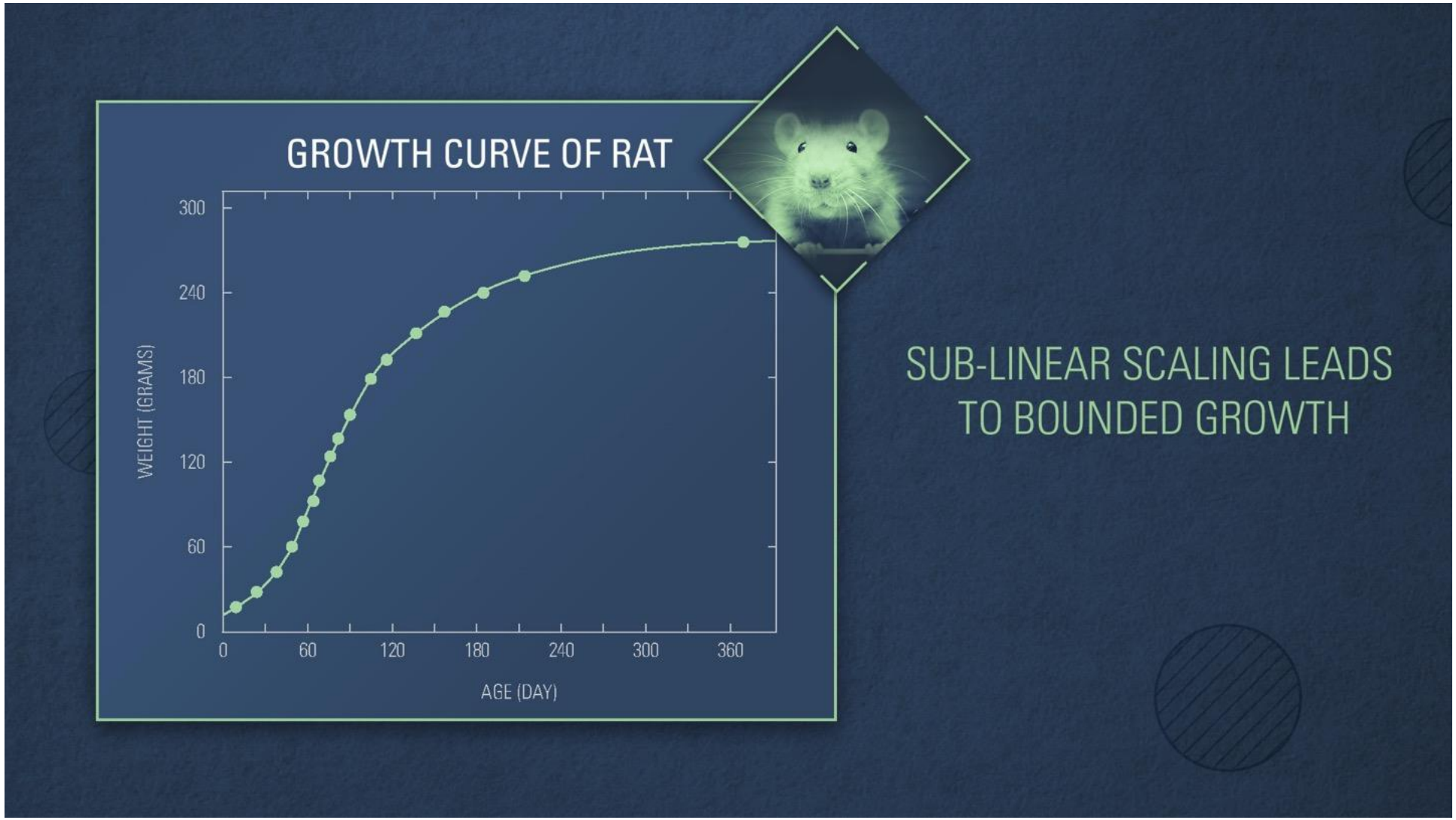
Growth Equation

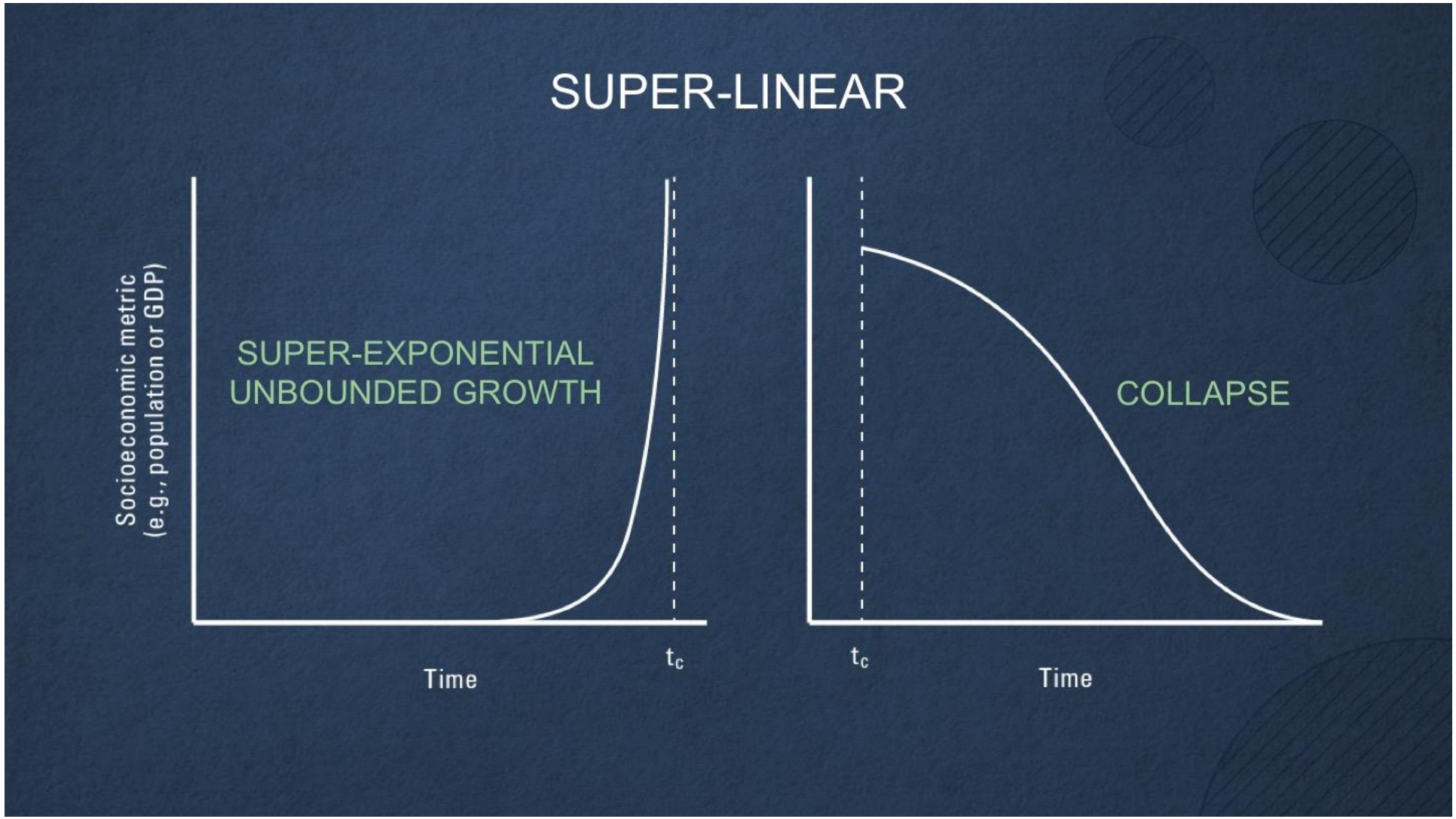
Incoming "Social Metabolic Rate"
(Resources, Products, Patents,… … "Energy" or "Dollar" equivalent)

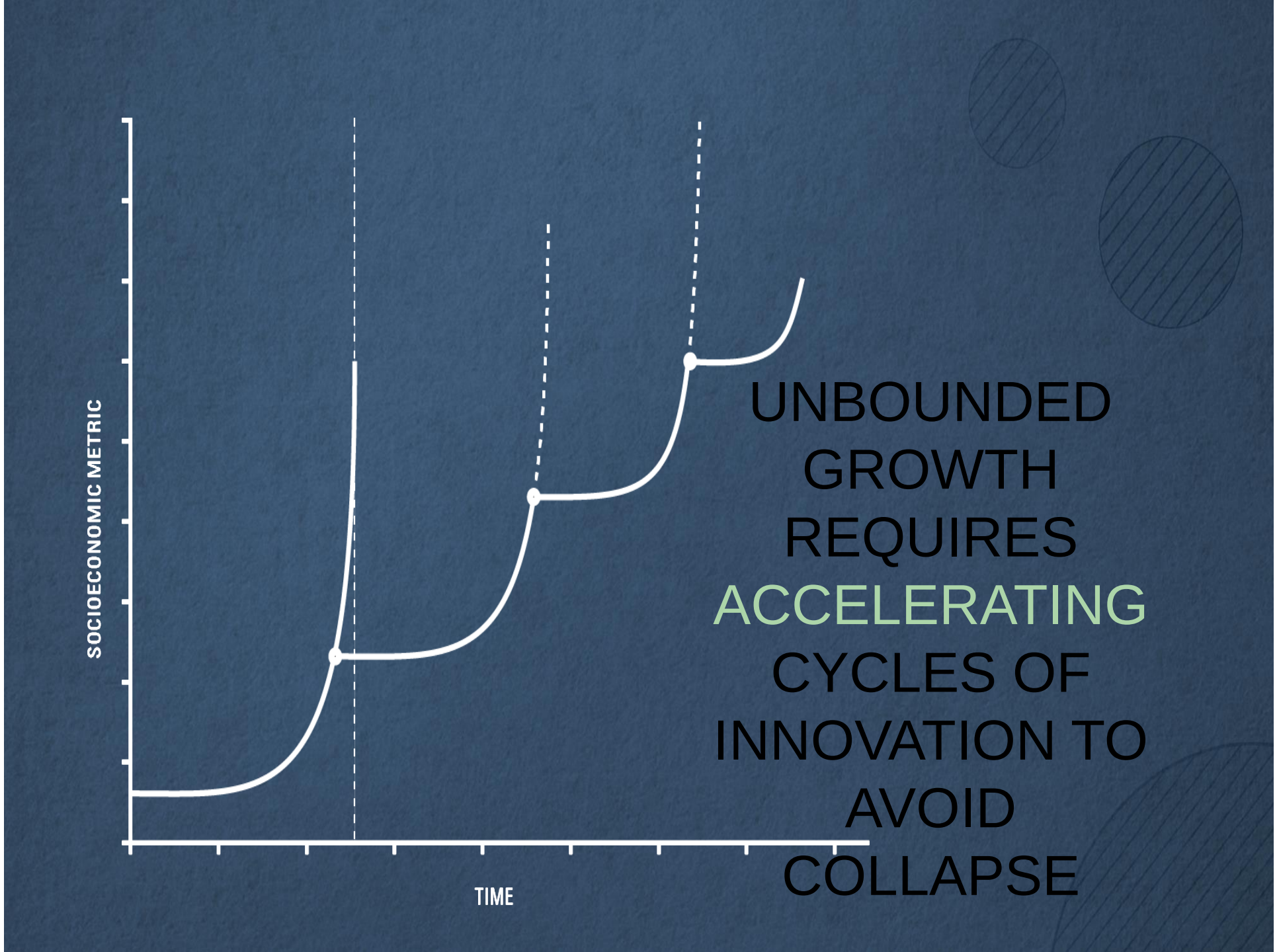
≈ **Maintenance** (Repair, Replacement, Sustenance, …)

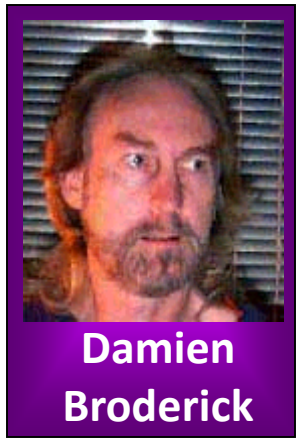
+

New Growth


GROWTH CURVE OF RAT
WEIGHT (GRAMS)
300
240
180
120
60
0
0
60
120
180
240
300
360
AGE (DAY)
SUB-LINEAR SCALING LEADS
TO BOUNDED GROWTH

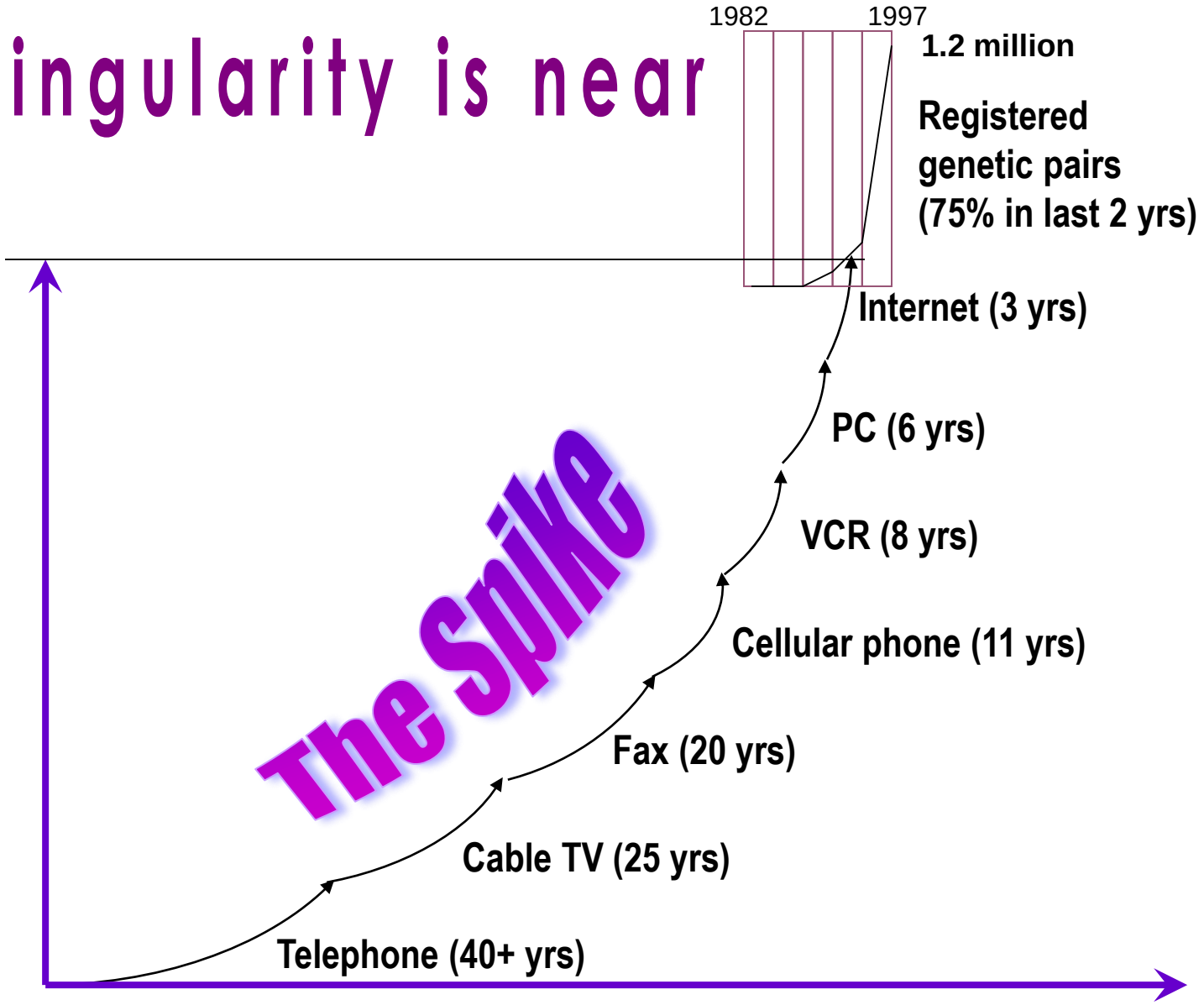

SUPER-LINEAR
Socioeconomic metric
(e.g., population or GDP)
SUPER-EXPONENTIAL
UNBOUNDED GROWTH
Time
t_c
t_c
COLLAPSE
Time

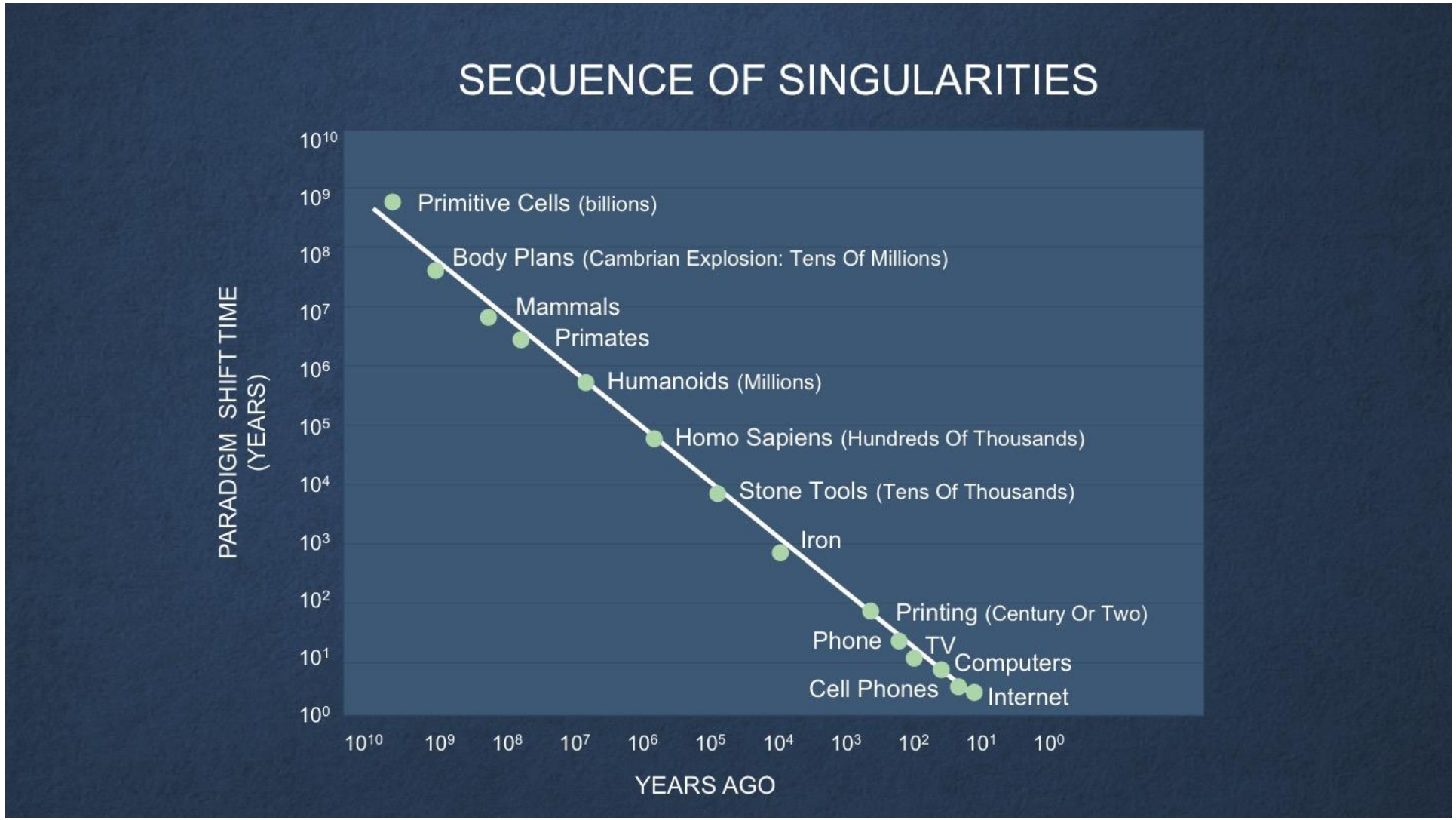

SOCIOECONOMIC METRIC
TIME
UNBOUNDED GROWTH REQUIRES ACCELERATING CYCLES OF INNOVATION TO AVOID COLLAPSE

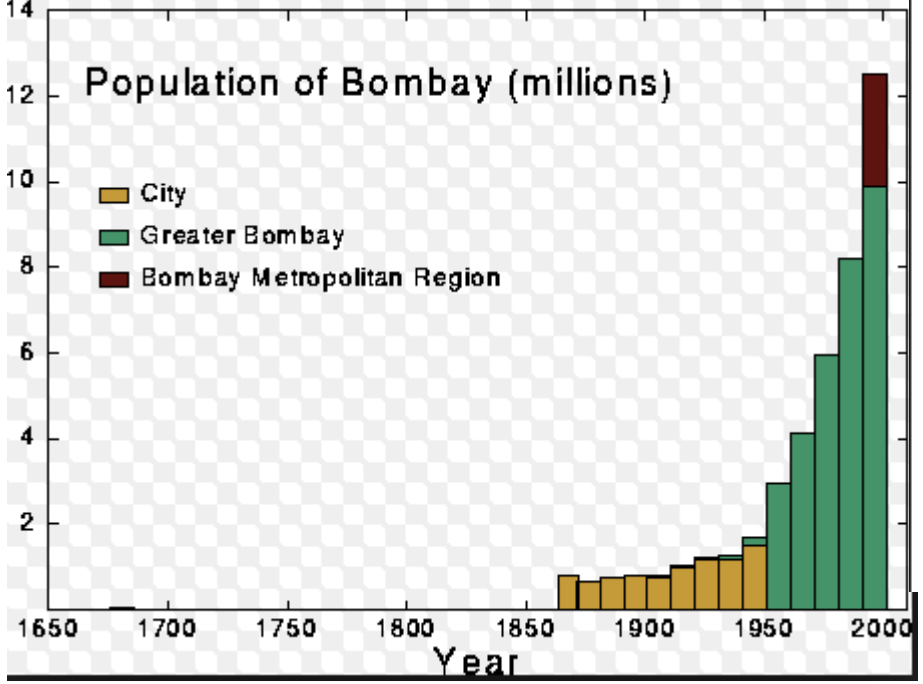


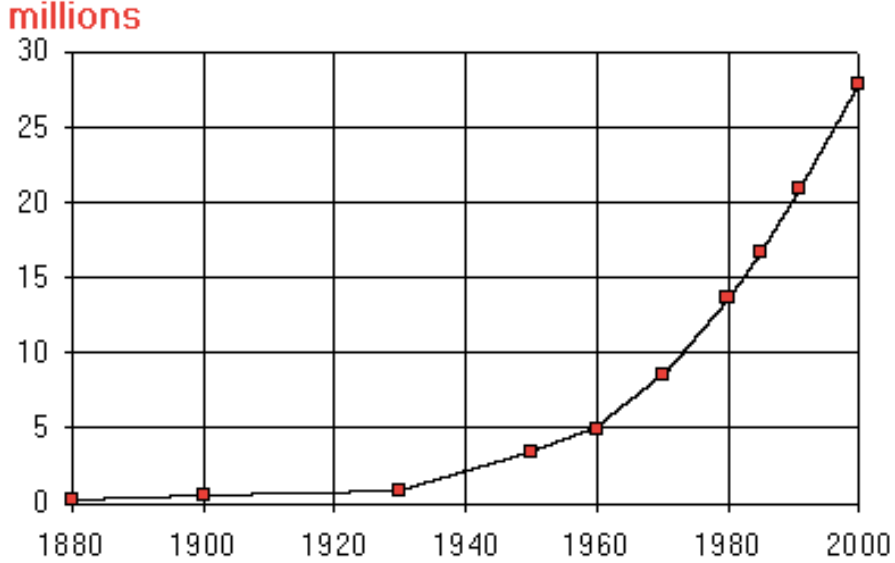
Damien Broderick

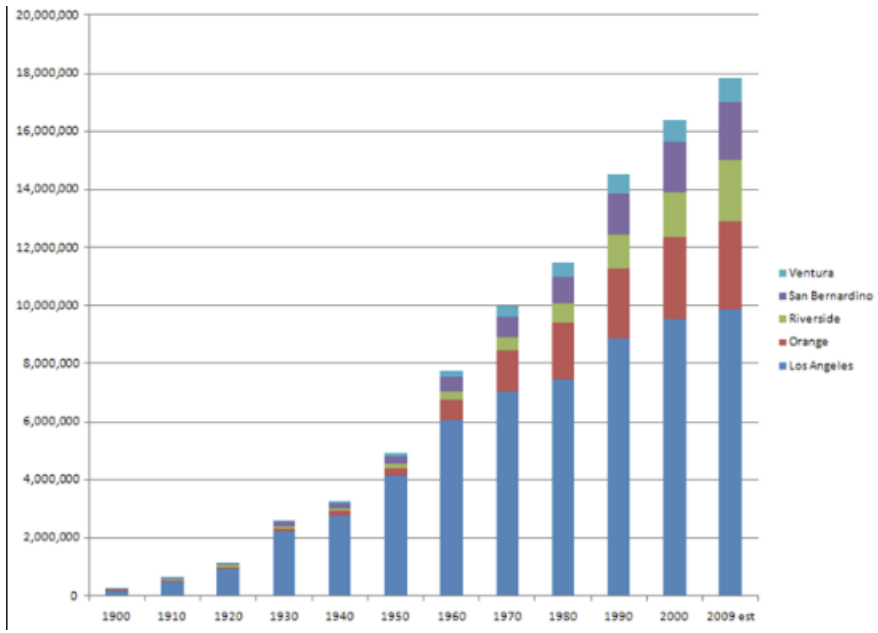
Singularity is near

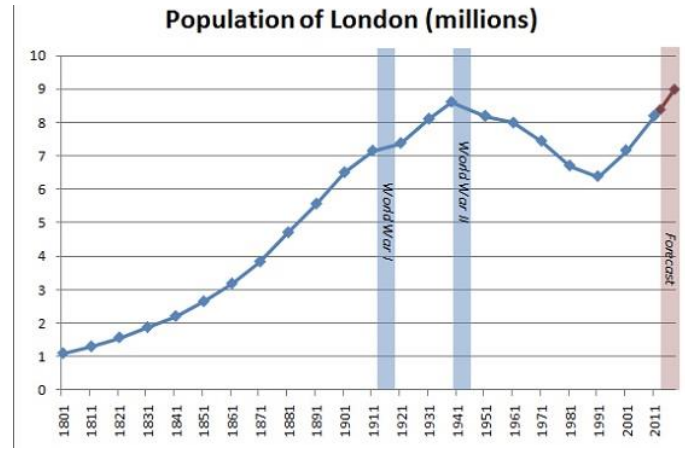


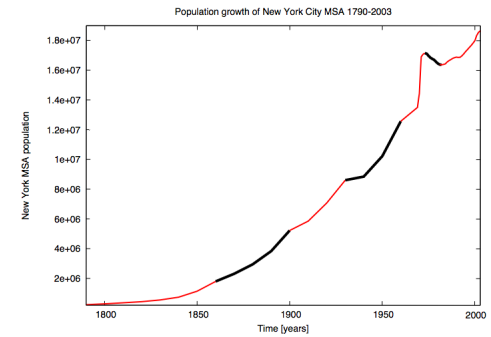

SEQUENCE OF SINGULARITIES
PARADIGM SHIFT TIME (YEARS)
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
Primitive Cells (billions)
Body Plans (Cambrian Explosion: Tens Of Millions)
Mammals
Primates
Humanoids (Millions)
Homo Sapiens (Hundreds Of Thousands)
Stone Tools (Tens Of Thousands)
Iron
Printing (Century Or Two)
Phone
TV
Computers
Cell Phones
Internet
10^{10} 10^{9} 10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10^{1} 10^{0}
YEARS AGO


Population of Bombay (millions)
City
Greater Bombay
Bombay Metropolitan Region
14
12
10
8
6
4
2
1650
1700
1750
1800
1850
1900
1950
2000
Year

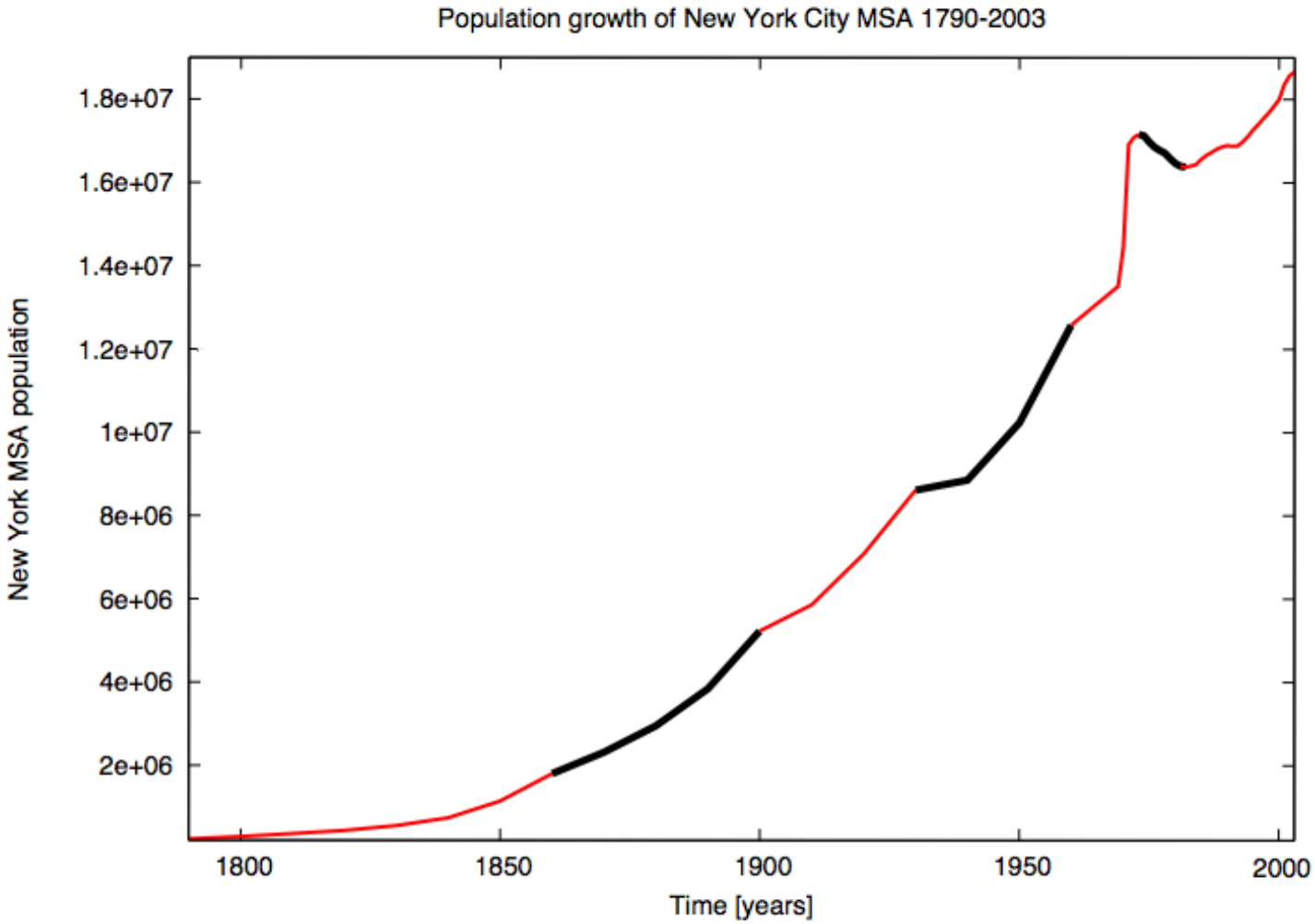

millions
30
25
20
15
10
5
0
1880
1900
1920
1940
1960
1980
2000

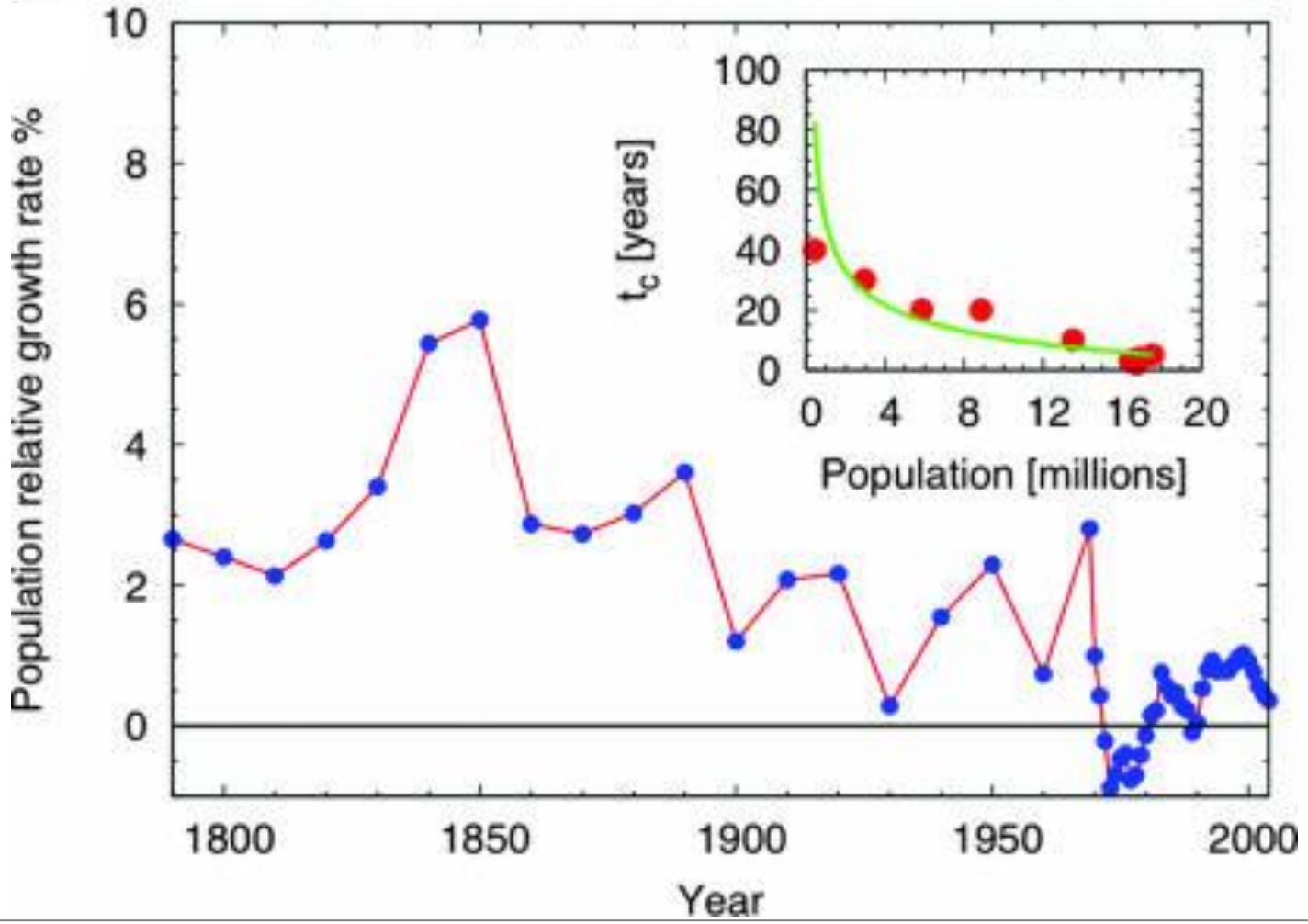

20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2009 est
Ventura
San Bernardino
Riverside
Orange
Los Angeles


Population of London (millions)
World War I
World War II
Forecast


Population growth of New York City MSA 1790-2003
New York MSA population
Time [years]

Population growth for New York City
1790 - 2003





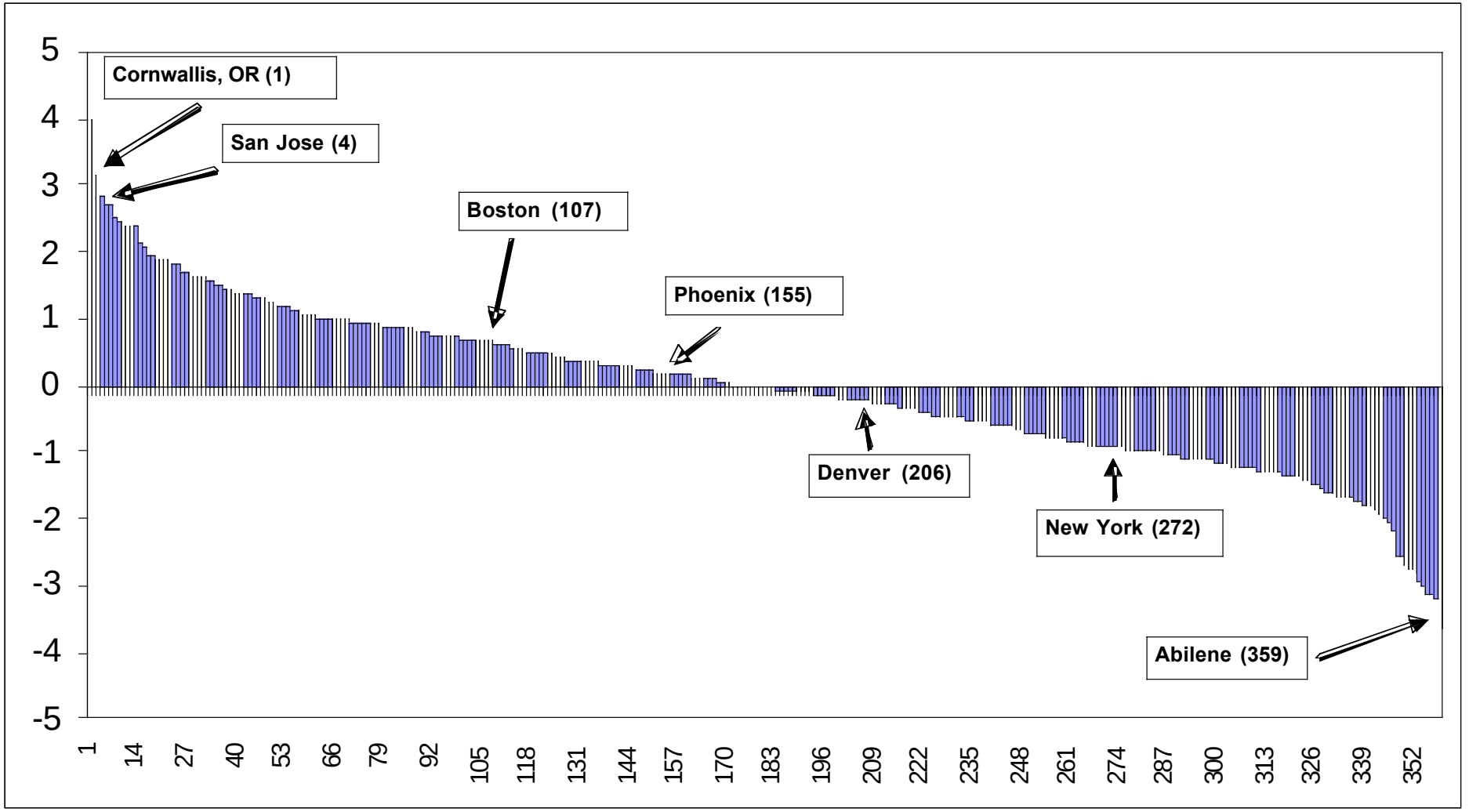
Successive cycles of superlinear innovation reset the singularity and postpone instability and subsequent collapse. The relative population growth rate of New York City over time reveals periods of accelerated (super-exponential) growth. Successive shorter periods of super exponential growth appear, separated by brief periods of deceleration. (Inset) t_c for each of these periods vs. population at the onset of the cycle. Observations are well fit with $\beta = 1.09$ (green line).

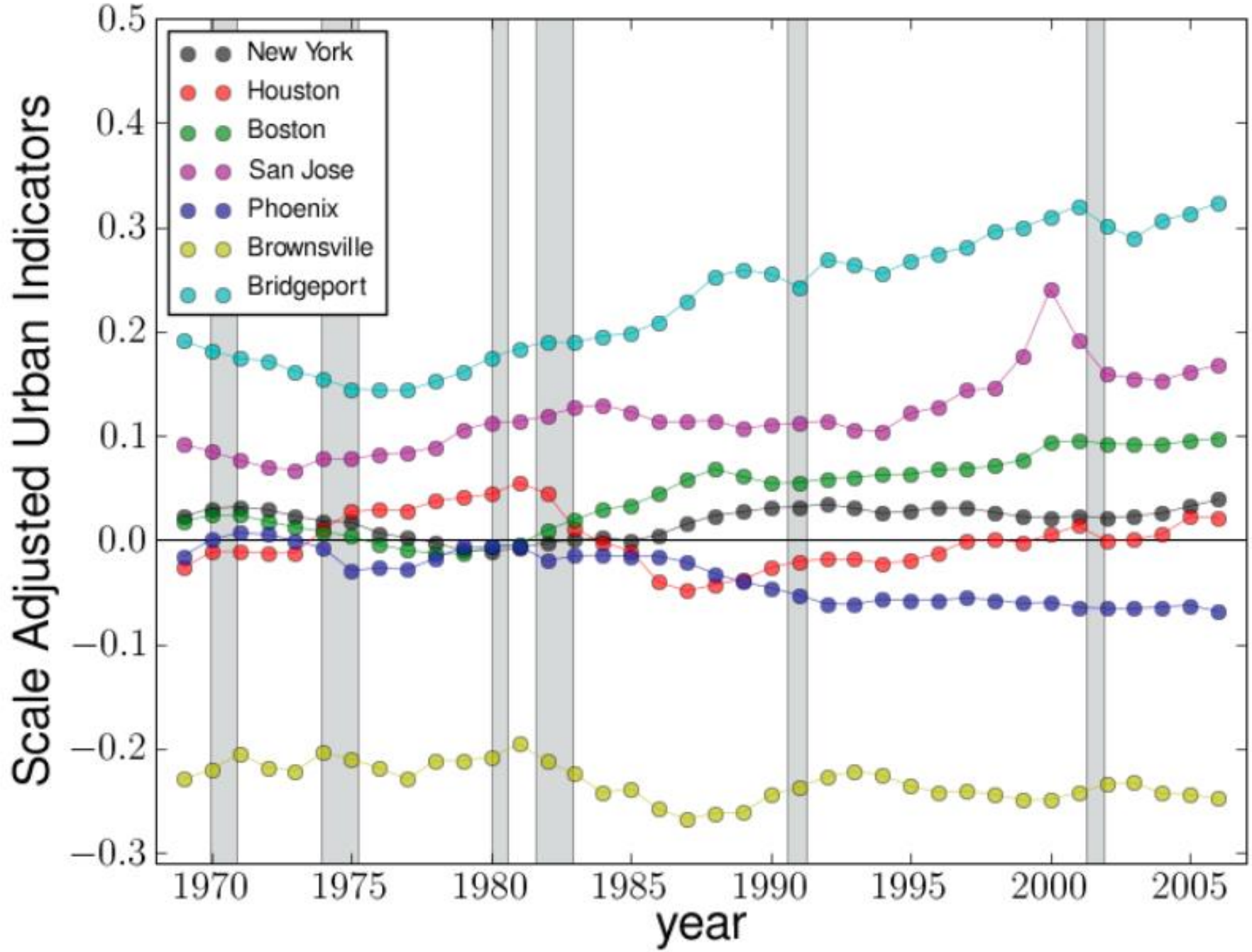
Average “idealised, universal” characteristics of cities of a given size (constrained by underlying principles and dynamics of network structures - manifested in scaling laws)

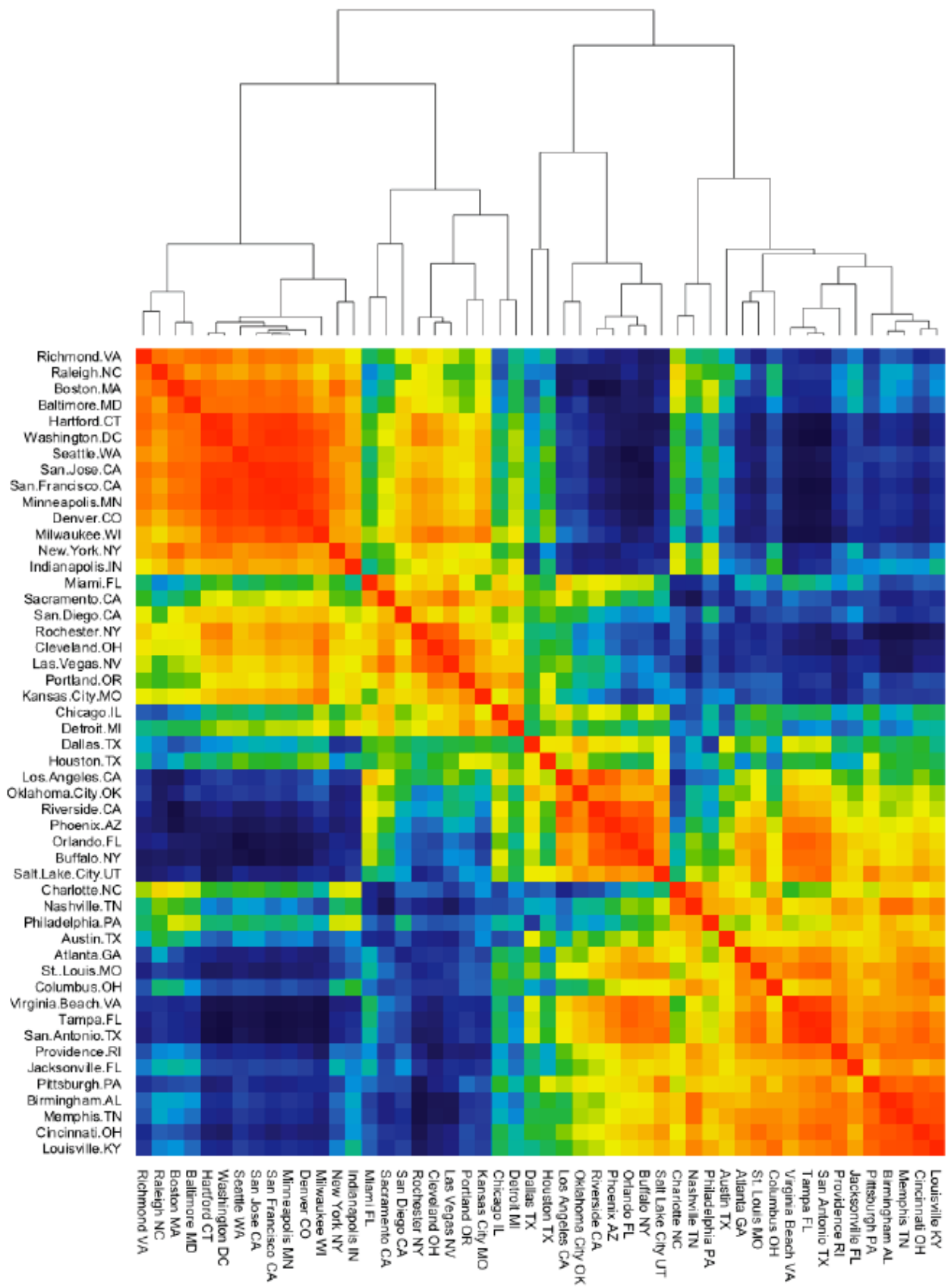
vs.

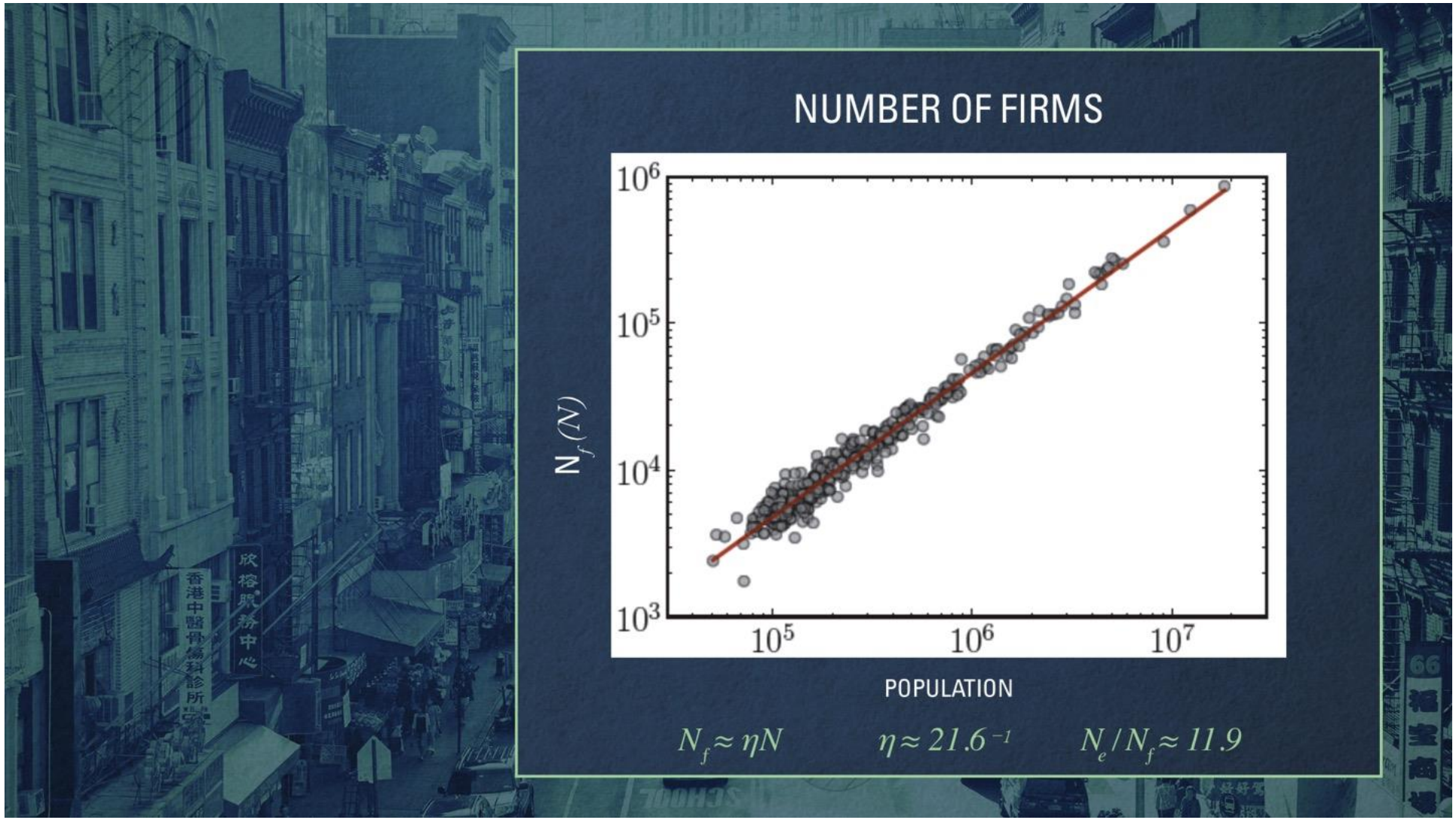
Characteristics of specific cities as measured by deviations from scaling laws representing their individuality and local environment and conditions

2003 Patenting Rankings




New York
Houston
Boston
San Jose
Phoenix
Brownsville
Bridgeport
Scale Adjusted Urban Indicators
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
1970
1975
1980
1985
1990
1995
2000
2005
year


Richmond.VA
Raleigh.NC
Boston.MA
Baltimore.MD
Hartford.CT
Washington.DC
Seattle.WA
San.Jose.CA
San.Francisco.CA
Minneapolis.MN
Denver.CO
Milwaukee.WI
New.York.NY
Indianapolis.IN
Miami.FL
Sacramento.CA
San.Diego.CA
Rochester.NY
Cleveland.OH
Las.Vegas.NV
Portland.OR
Kansas.City.MO
Chicago.IL
Detroit.MI
Dallas.TX
Houston.TX
Los.Angeles.CA
Oklahoma.City.OK
Riverside.CA
Phoenix.AZ
Orlando.FL
Buffalo.NY
Salt.Lake.City.UT
Charlotte.NC
Nashville.TN
Philadelphia.PA
Austin.TX
Atlanta.GA
St..Louis.MO
Columbus.OH
Virginia.Beach.VA
Tampa.FL
San.Antonio.TX
Providence.RI
Jacksonville.FL
Pittsburgh.PA
Birmingham.AL
Memphis.TN
Cincinnati.OH
Louisville.KY
Richmond VA
Raleigh NC
Boston MA
Baltimore MD
Hartford CT
Washington DC
Seattle WA
San Jose CA
San Francisco CA
Minneapolis MN
Denver CO
Milwaukee WI
New York NY
Indianapolis IN
Miami FL
Sacramento CA
San Diego CA
Rochester NY
Cleveland OH
Las Vegas NV
Portland OR
Kansas City MO
Chicago IL
Detroit MI
Dallas TX
Houston TX
Los Angeles CA
Oklahoma City OK
Riverside CA
Phoenix AZ
Orlando FL
Buffalo NY
Salt Lake City UT
Charlotte NC
Nashville TN
Philadelphia PA
Austin TX
Atlanta GA
St. Louis MO
Columbus OH
Virginia Beach VA
Tampa FL
San Antonio TX
Providence RI
Jacksonville FL
Pittsburgh PA
Birmingham AL
Memphis TN
Cincinnati OH
Louisville KY


NUMBER OF FIRMS
10^6
10^5
10^4
10^3
$N_f(N)$
10^5
10^6
10^7
POPULATION
$N_f \approx \eta N$
$\eta \approx 21.6^{-1}$
$N_e / N_f \approx 11.9$

SO, ON AVERAGE, EACH TIME THE POPULATION INCREASES BY ABOUT 21 PEOPLE, A NEW BUSINESS IS ADDED, REGARDLESS OF CITY SIZE!!

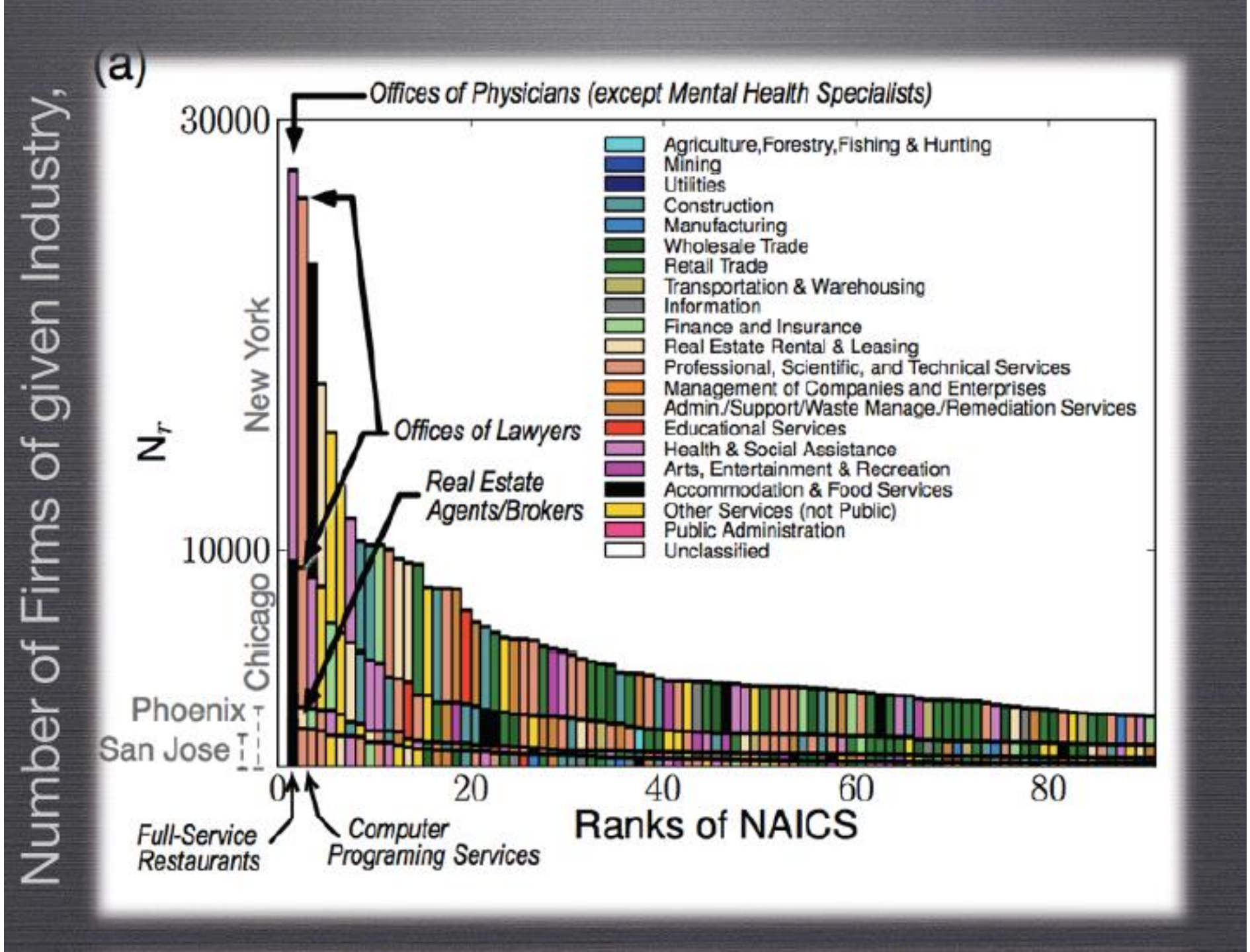
SO, ON AVERAGE, EACH TIME THE POPULATION INCREASES BY ABOUT 21 PEOPLE, A NEW BUSINESS IS ADDED, REGARDLESS OF CITY SIZE!!

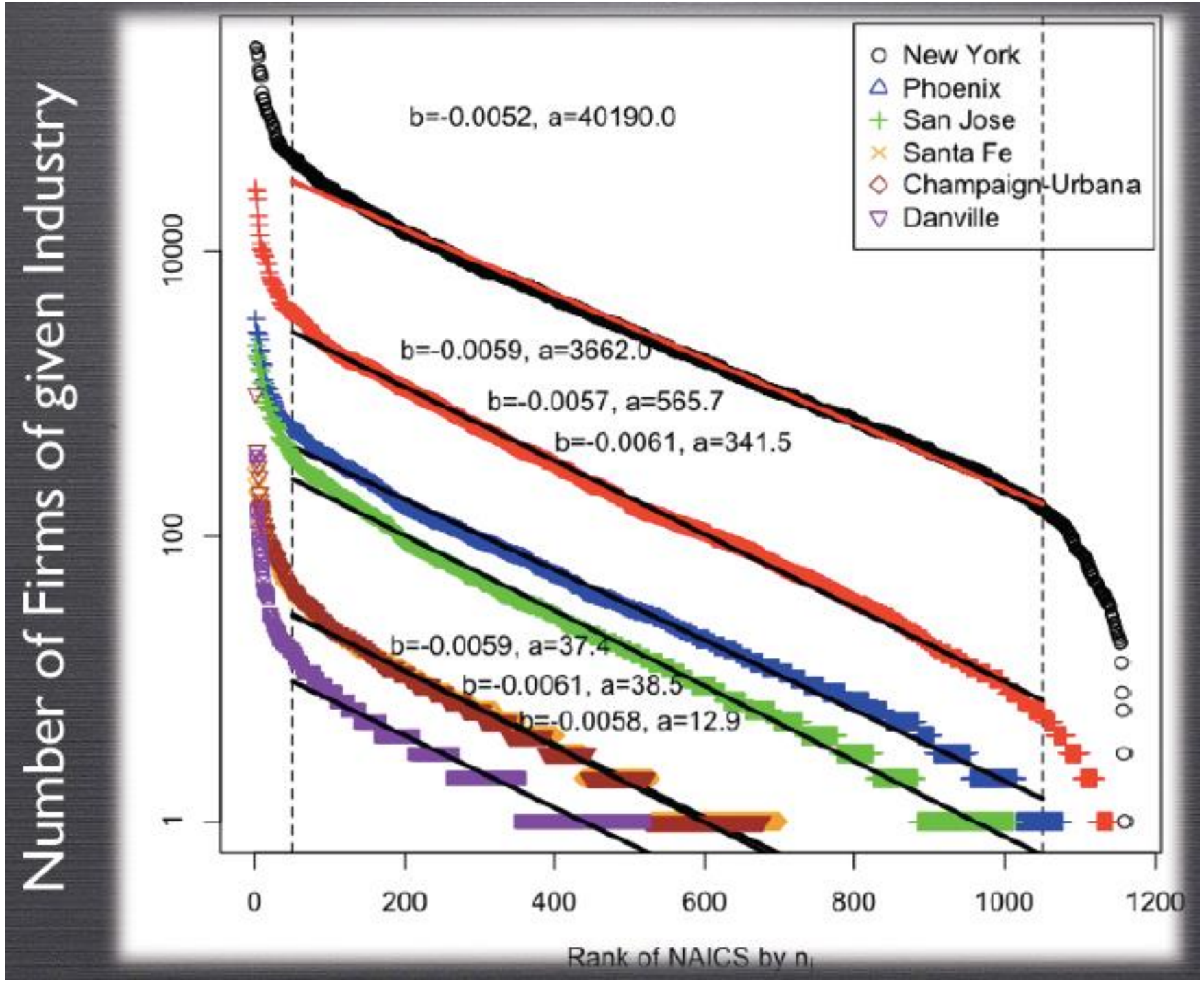
AND

SO, ON AVERAGE, EACH TIME THE POPULATION INCREASES BY ABOUT 21 PEOPLE, A NEW BUSINESS IS ADDED, REGARDLESS OF CITY SIZE!!

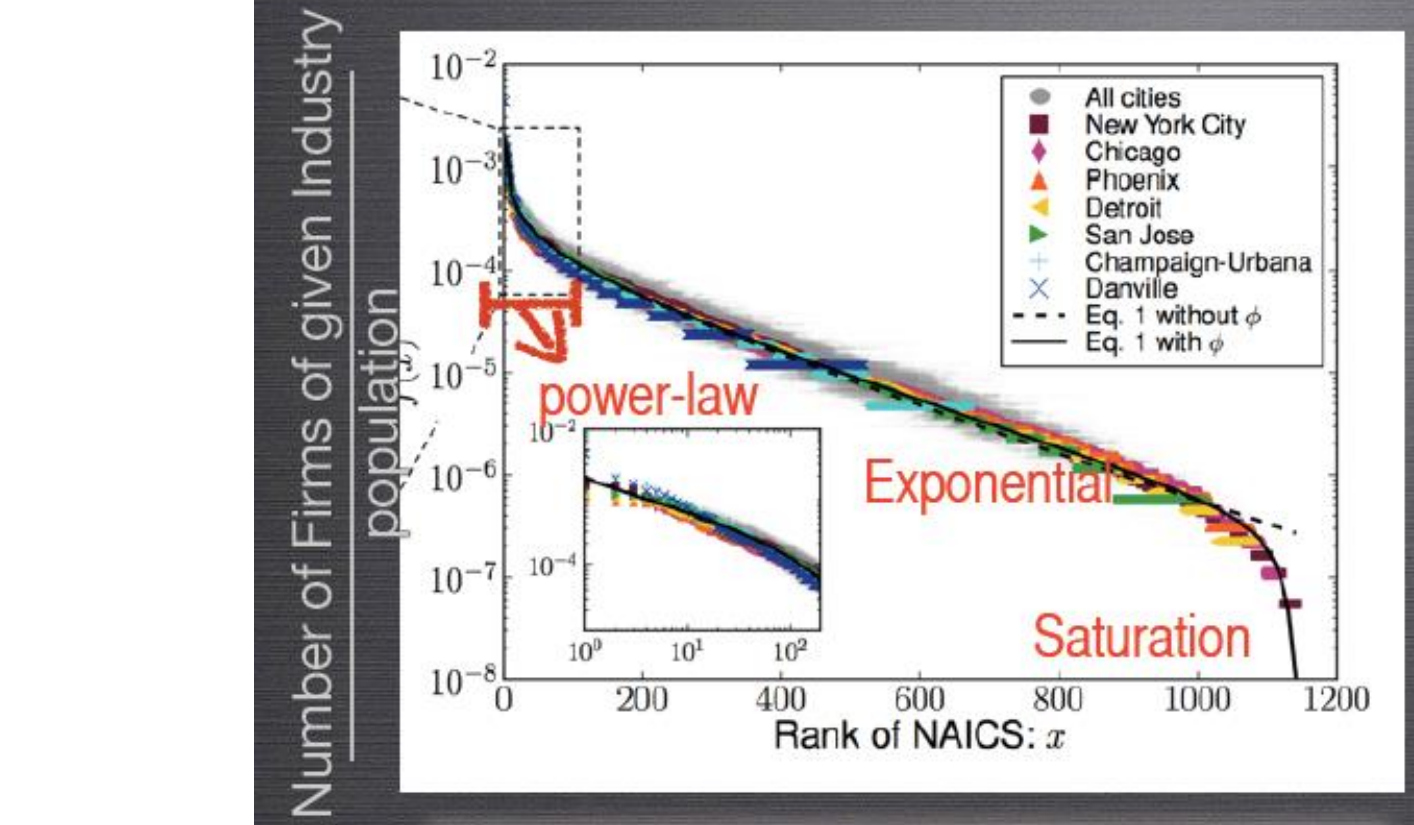
AND

ON AVERAGE, EACH BUSINESS EMPLOYS ABOUT 12 PEOPLE


(a)
Offices of Physicians (except Mental Health Specialists)
30000
10000
New York
Chicago
Phoenix
San Jose
N_r
Offices of Lawyers
Real Estate Agents/Brokers
Agriculture,Forestry,Fishing & Hunting
Mining
Utilities
Construction
Manufacturing
Wholesale Trade
Retail Trade
Transportation & Warehousing
Information
Finance and Insurance
Real Estate Rental & Leasing
Professional, Scientific, and Technical Services
Management of Companies and Enterprises
Admin./Support/Waste Manage./Remediation Services
Educational Services
Health & Social Assistance
Arts, Entertainment & Recreation
Accommodation & Food Services
Other Services (not Public)
Public Administration
Unclassified
0
20
40
60
80
Ranks of NAICS
Full-Service Restaurants
Computer Programing Services
Number of Firms of given Industry,


Number of Firms of given Industry
New York
Phoenix
San Jose
Santa Fe
Champaign-Urbana
Danville
b=-0.0052, a=40190.0
b=-0.0059, a=3662.0
b=-0.0057, a=565.7
b=-0.0061, a=341.5
b=-0.0059, a=37.4
b=-0.0061, a=38.5
b=-0.0058, a=12.9
10000
100
1
0
200
400
600
800
1000
1200
Rank of NAICS by n_i

Universal Distribution



$$p(x) \sim x^{-0.5}\, e^{-x/170}\, \phi\,(x, D_{max})$$

- Regardless of **Density** and **Wealth**
- underlying dynamics for interactions of businesses
- Generalized Simon-Yule Model:

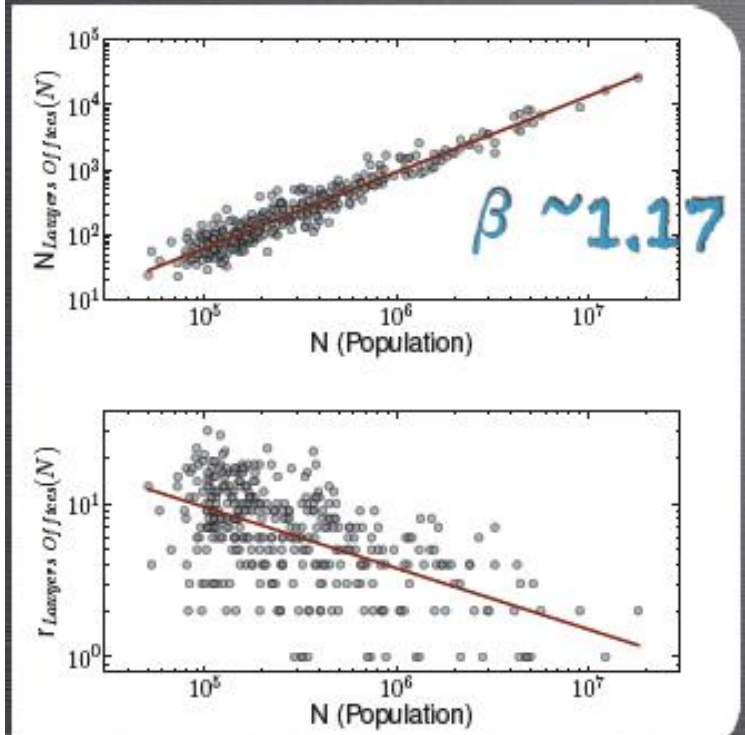
$$\rho(N) = \frac{N\alpha(N)}{D(N)} \frac{1}{1-\alpha(N)}$$

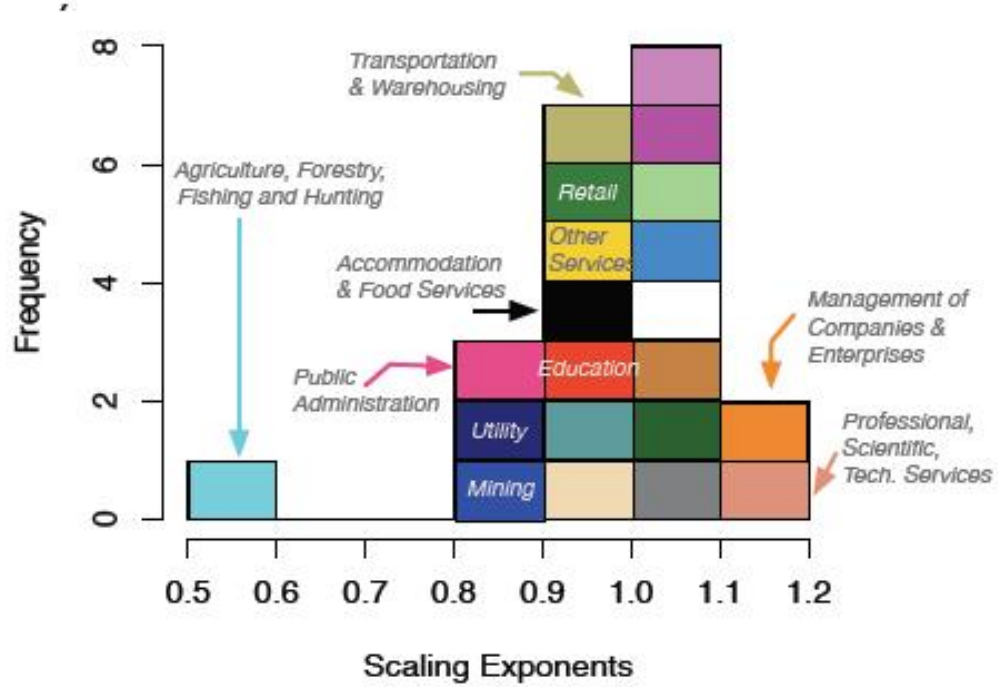
$\alpha \sim 0.5$ *when small* N

$$\rho = 1/\gamma = 1 - \alpha$$

$$\alpha\,(N) = dD(N)/dN \approx x_0/N$$

Systematic Shift of Sectors





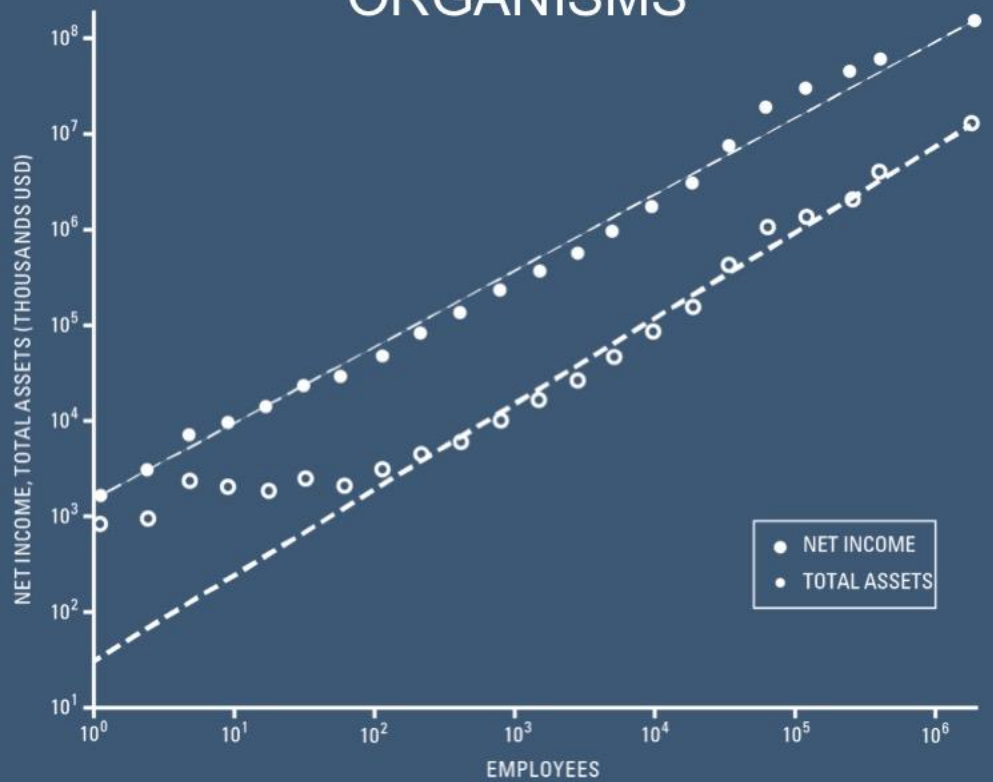
GDP INCREASES EXPONENTIALLY WITH DIVERSITY

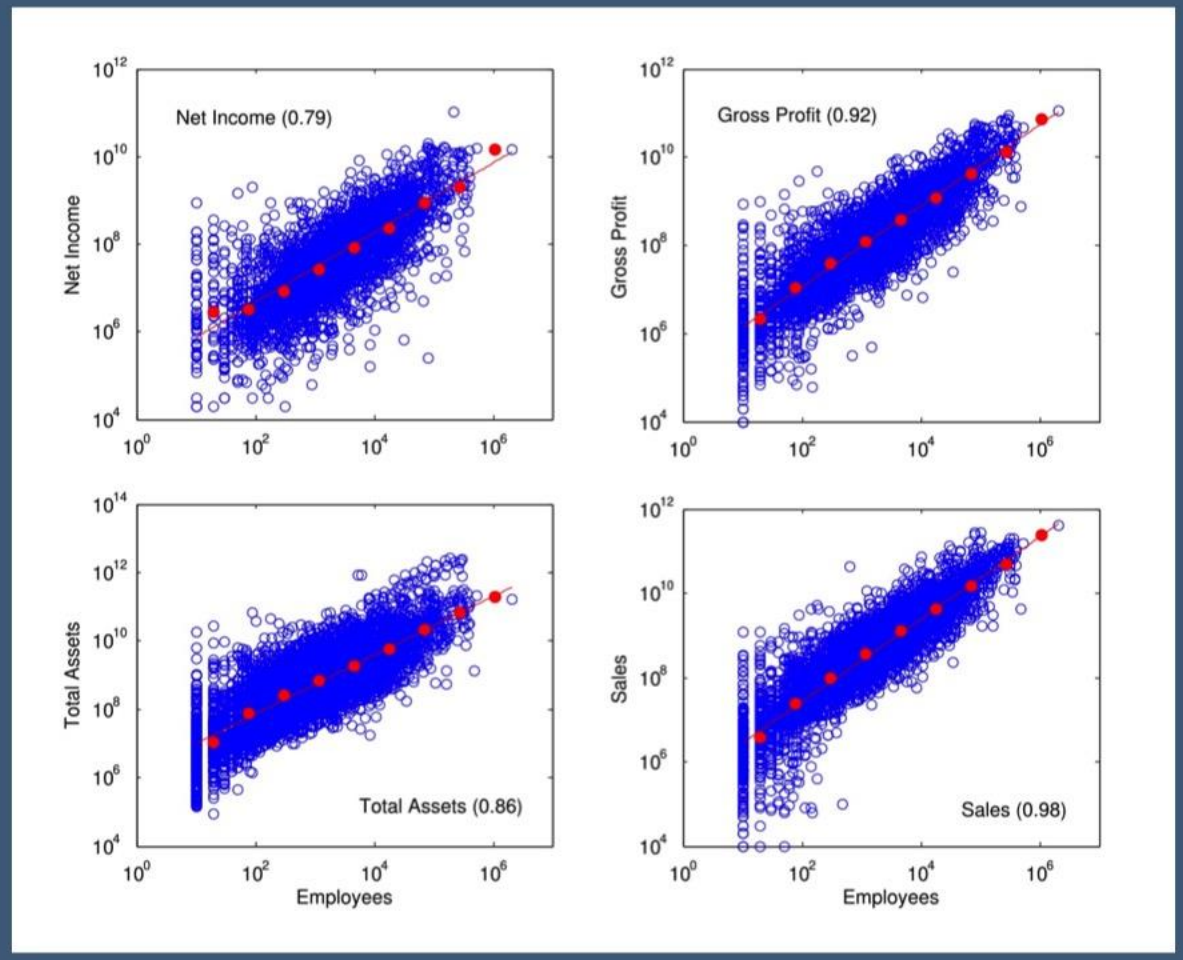
(AND AS A POWER LAW WITH POPULATION SIZE)

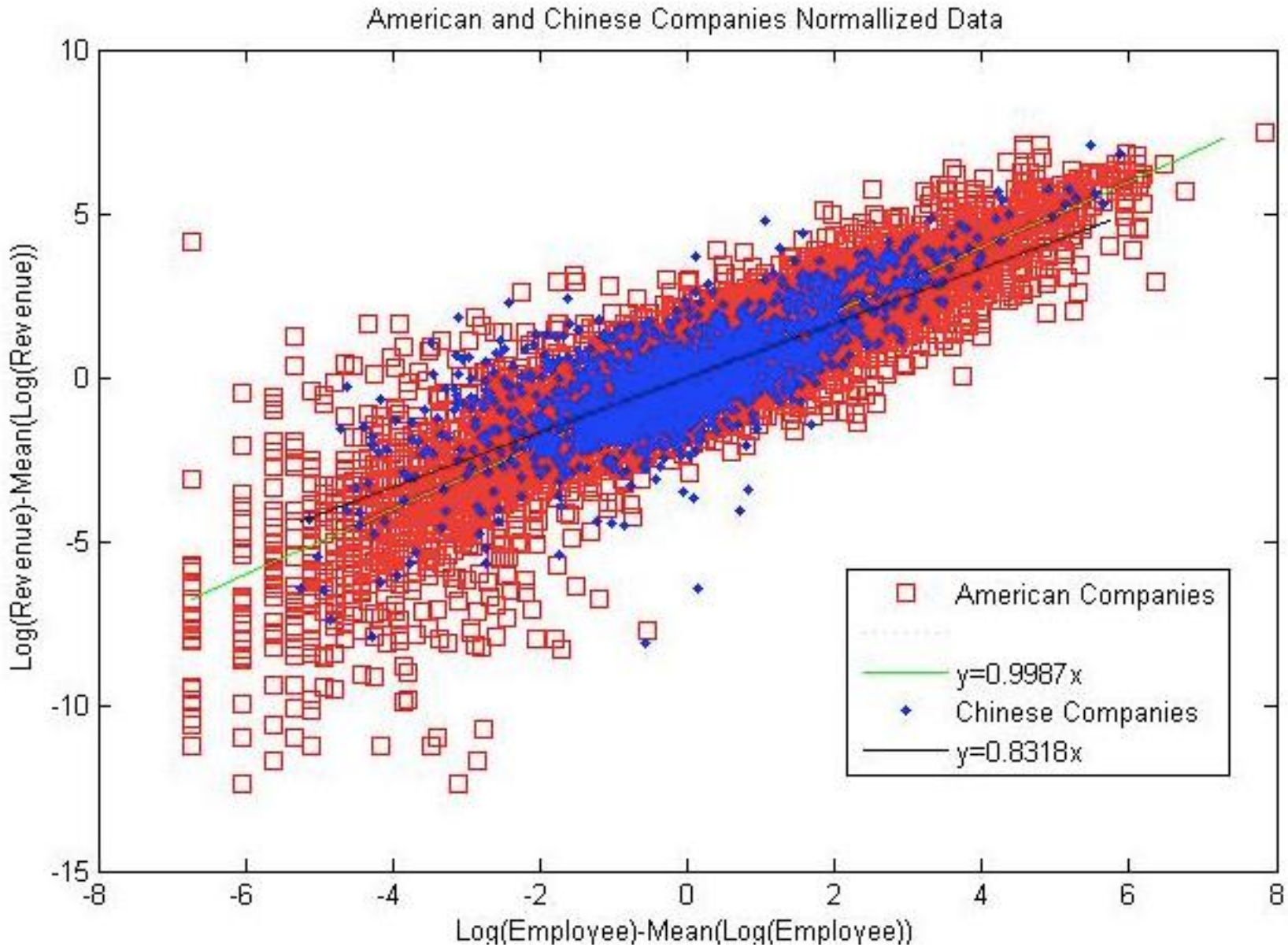
GDP INCREASES EXPONENTIALLY WITH DIVERSITY

WITH EACH ADDITIONAL BUSINESS CATEGORY, GDP INCREASES BY ~ 0.5%

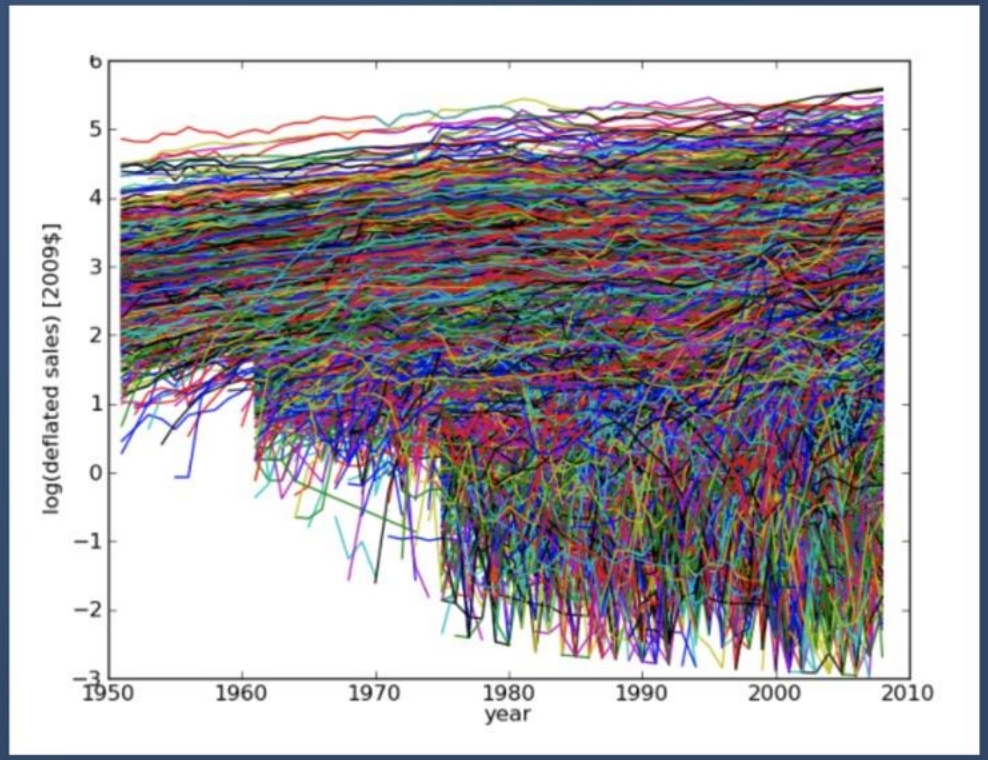
COMPANIES SCALE SUB-LINEARLY ANALOGOUS TO ORGANISMS



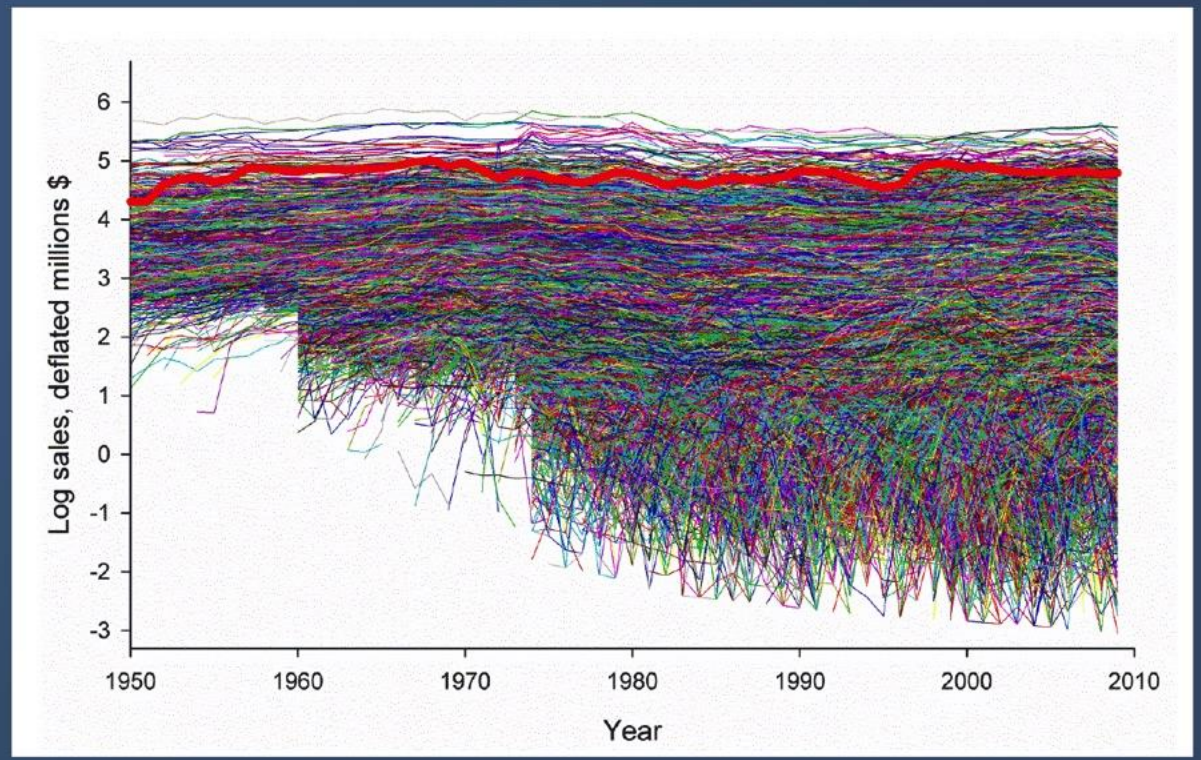

Net Income (0.79)
Net Income
Gross Profit (0.92)
Gross Profit
Total Assets (0.86)
Total Assets
Sales (0.98)
Sales
Employees
Employees


American and Chinese Companies Normallized Data
Log(Revenue)-Mean(Log(Revenue))
Log(Employee)-Mean(Log(Employee))
10
5
0
-5
-10
-15
-8
-6
-4
-2
0
2
4
6
8
American Companies
y=0.9987x
Chinese Companies
y=0.8318x

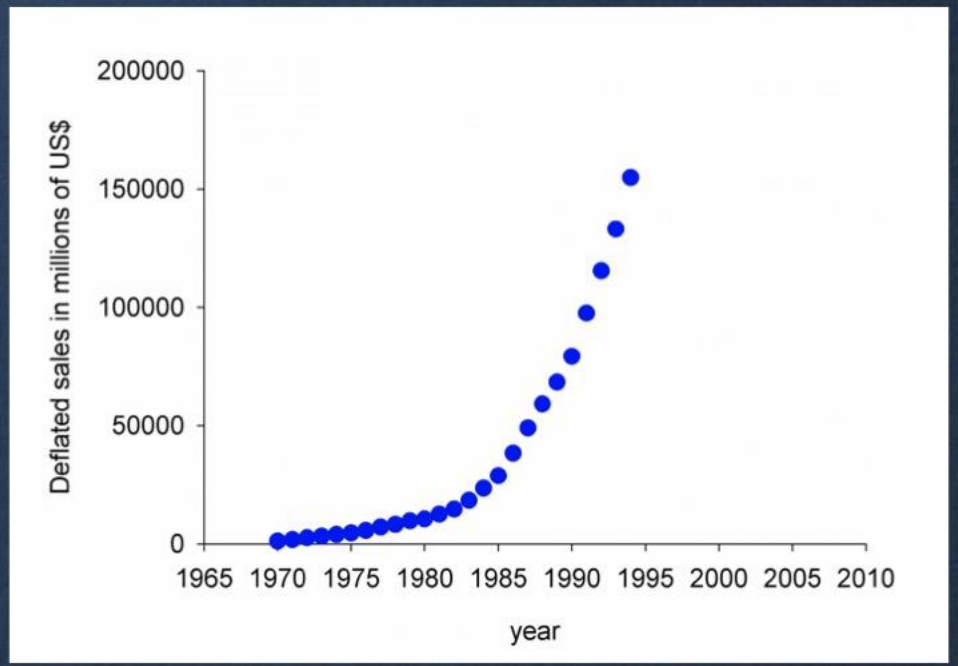
GROWTH OF FIRMS



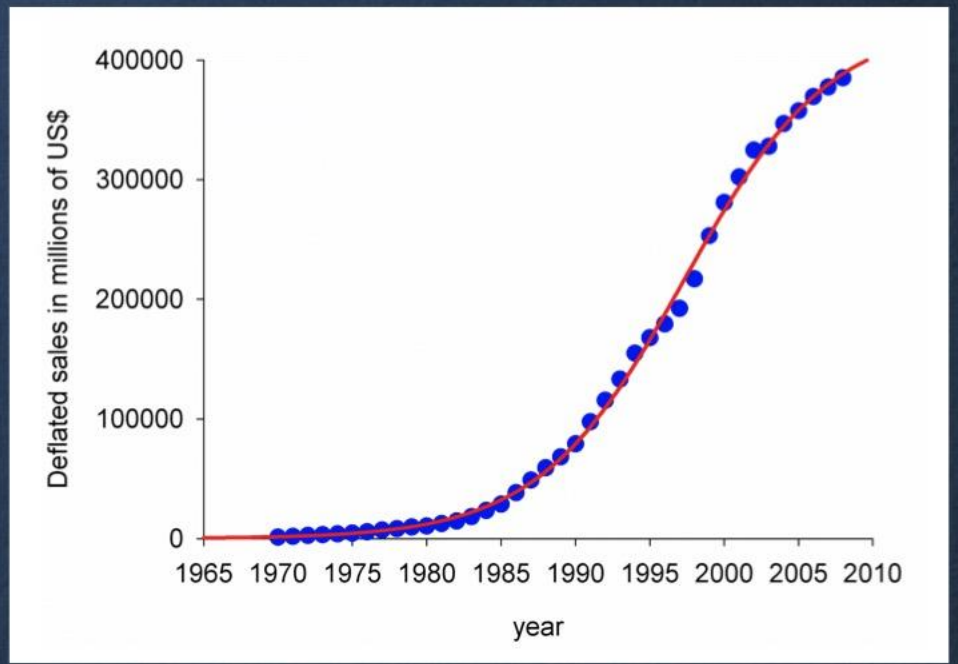
GROWTH OF FIRMS RELATIVE TO GDP

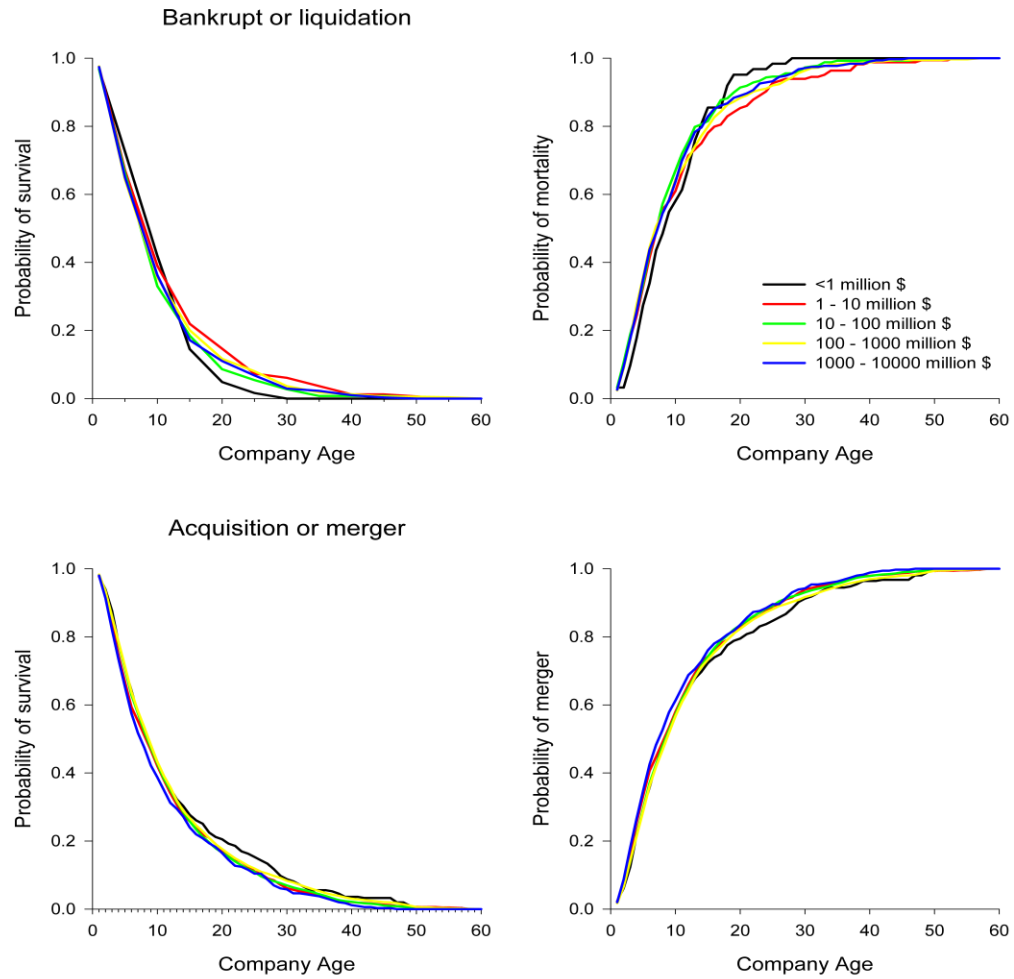


WALMART, 1970-1994



WALMART, 1970-2008



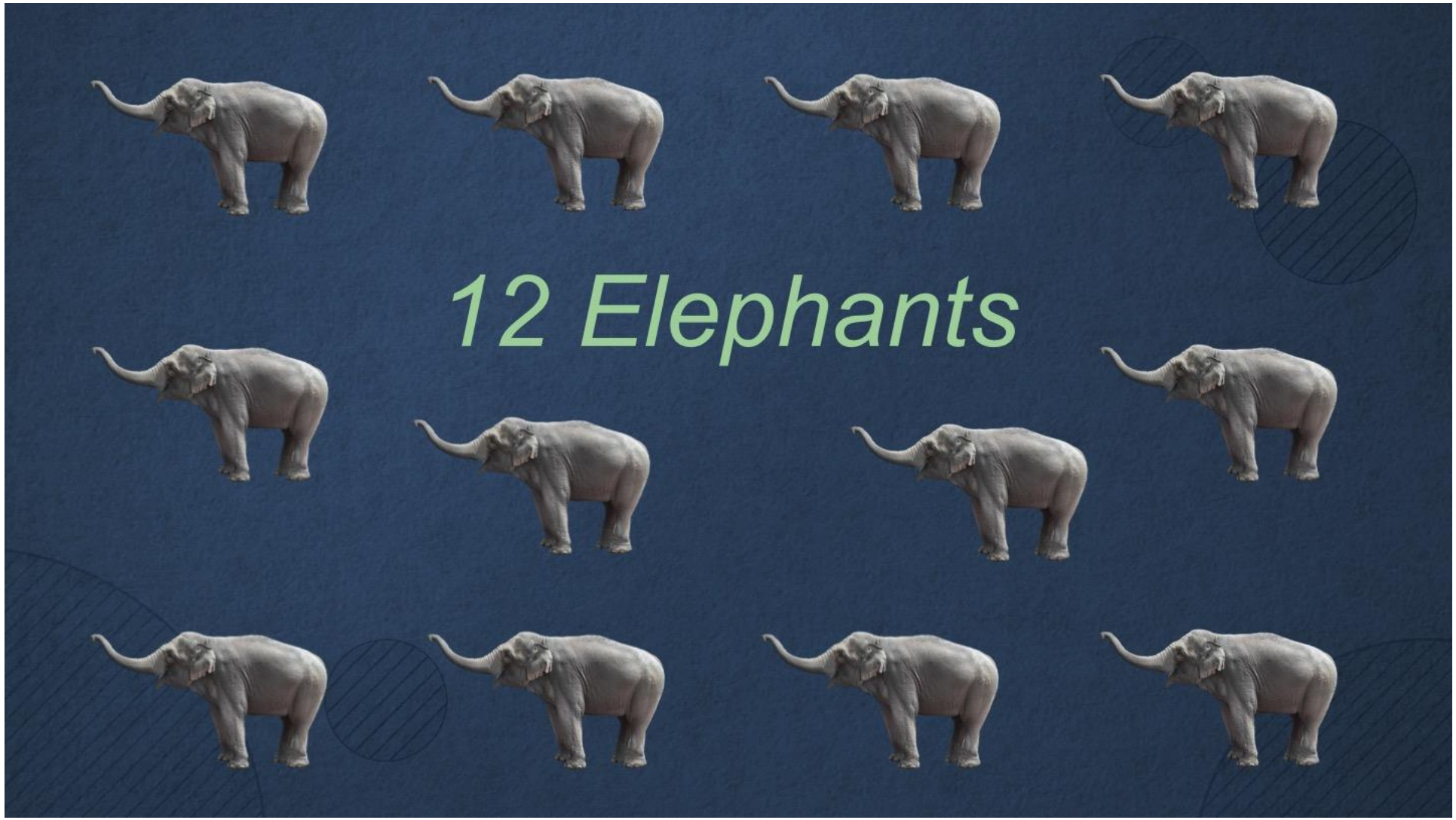

Bankrupt or liquidation
Probability of survival
Company Age
Probability of mortality
Company Age
<1 million $
1 - 10 million $
10 - 100 million $
100 - 1000 million $
1000 - 10000 million $
Acquisition or merger
Probability of survival
Company Age
Probability of merger
Company Age

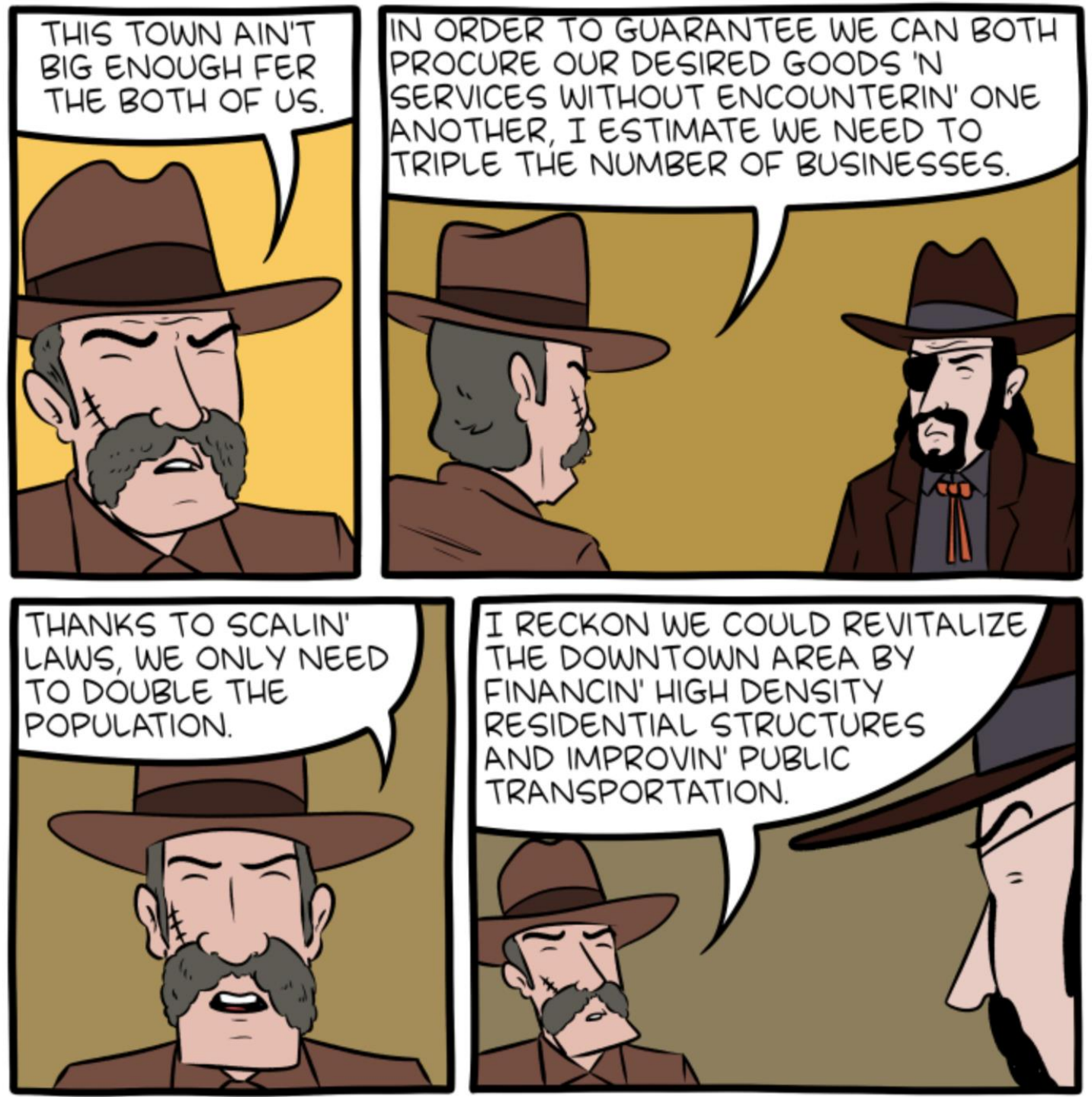
Our “natural” metabolic rate *~90 watts*

Our social metabolic rate *~11,000 watts*

We are equivalent to a

30,000 kg Gorilla


12 Elephants


THIS TOWN AIN'T BIG ENOUGH FER THE BOTH OF US.
IN ORDER TO GUARANTEE WE CAN BOTH PROCURE OUR DESIRED GOODS 'N SERVICES WITHOUT ENCOUNTERIN' ONE ANOTHER, I ESTIMATE WE NEED TO TRIPLE THE NUMBER OF BUSINESSES.
THANKS TO SCALIN' LAWS, WE ONLY NEED TO DOUBLE THE POPULATION.
I RECKON WE COULD REVITALIZE THE DOWNTOWN AREA BY FINANCIN' HIGH DENSITY RESIDENTIAL STRUCTURES AND IMPROVIN' PUBLIC TRANSPORTATION.