Contingent Correlations – An Exploration of Health Inequalities in the U.S. and Canada

"an aggregate relation between income inequality and health is not necessary — associations are contingent" (Lynch et al., BMJ, 2000)

Michael Wolfson, uOttawa

Caution: Sometimes Geeky ☺

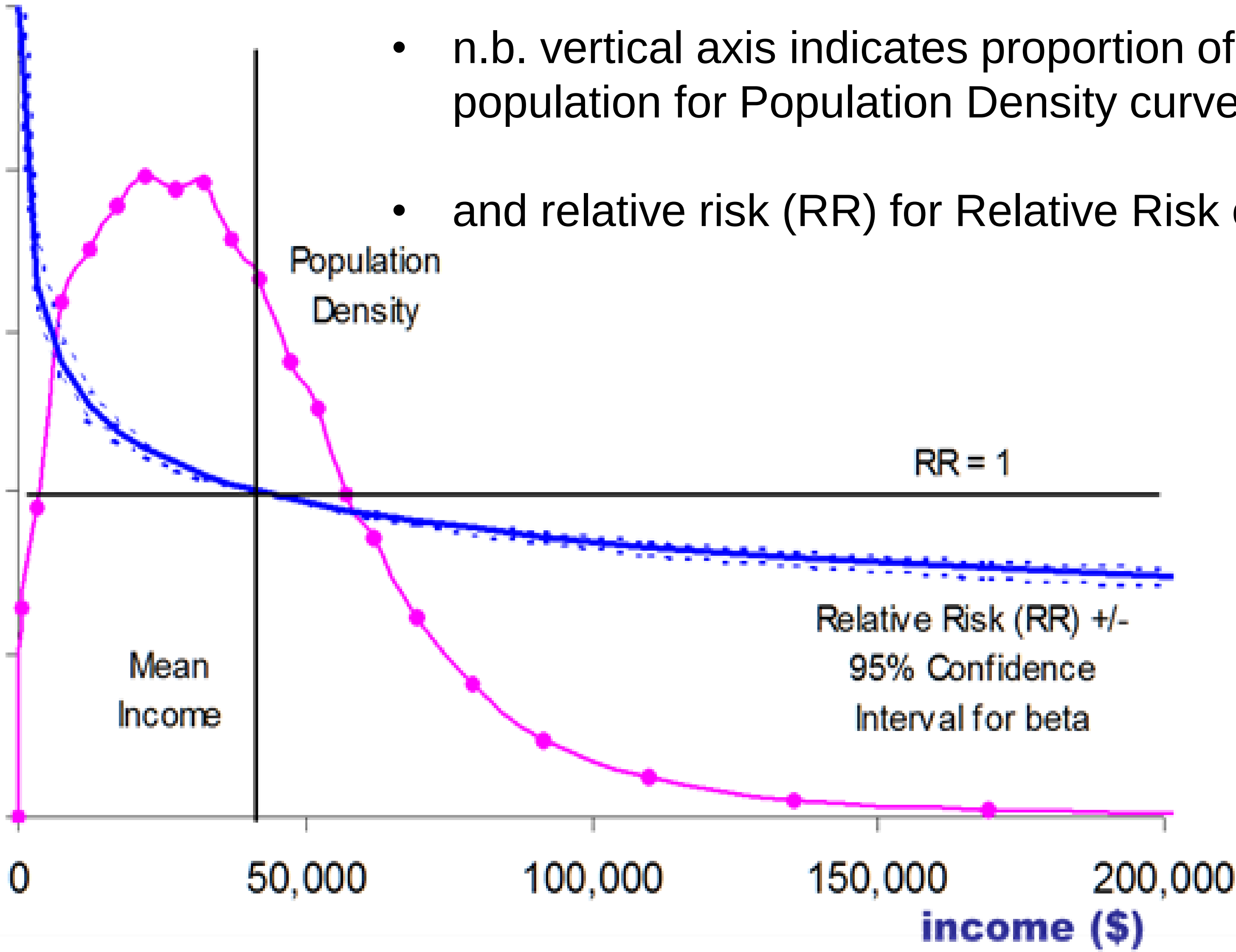
special thanks to Reed Beall, Steve Gribble and George Kaplan; funding from the NIH Network for Inequality, Complexity and Health

Problematique

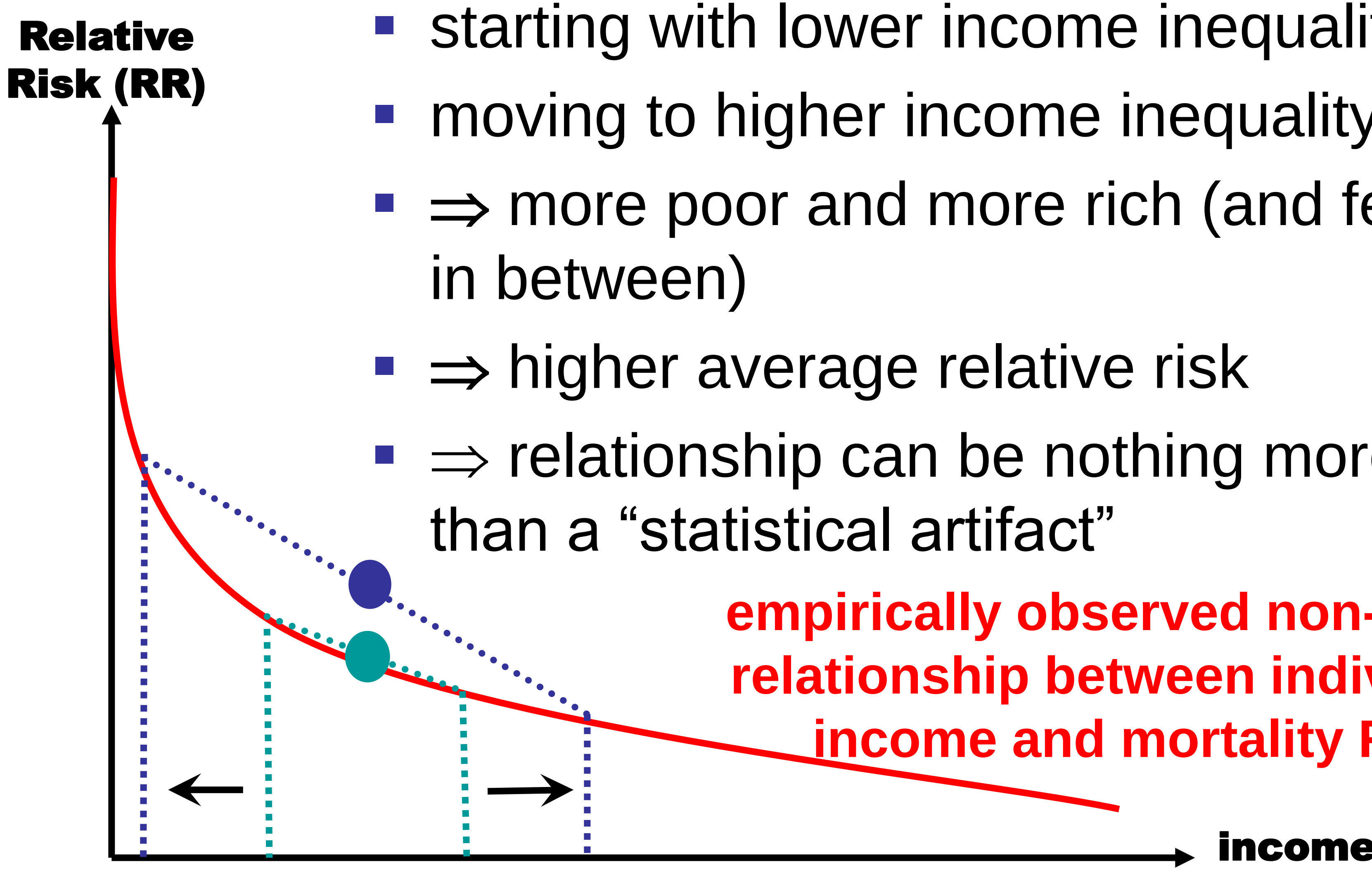
- there is continuing and unresolved debate in the social epidemiological literature about whether or not higher income inequality → poorer health
- also continuing confusion about individual-level income differences, and income inequality which is a characteristic of a population
- many researchers persist in using single equation regression (statistical) models, but:
  - various levels of analysis: counties ↔ countries
  - single year cross-section ↔ multiple years
  - also repeated cross-section ↔ longitudinal
  - various times lags: income inequality → health
  - multi-level aspect generally ignored

Income Distribution and Individual Mortality Relative Risk, US 1991

- n.b. vertical axis indicates proportion of population for Population Density curve,
- and relative risk (RR) for Relative Risk curve



Challenge: Ecological Confusion re Individual and Population Inequality



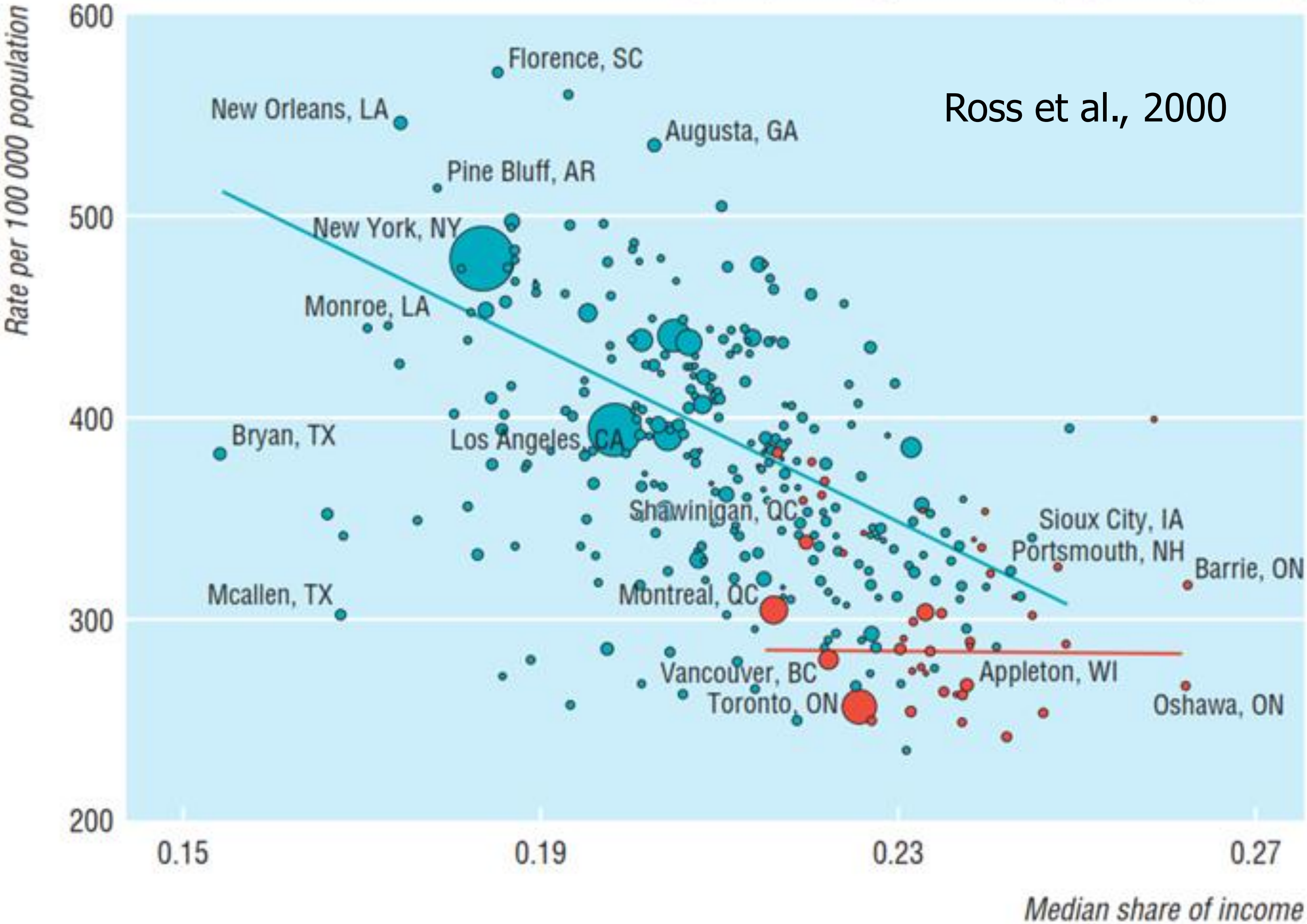
- starting with lower income inequality ( )
- moving to higher income inequality ( )
- ⇒ more poor and more rich (and fewer in between)
- ⇒ higher average relative risk
- ⇒ relationship can be nothing more than a “statistical artifact”

empirically observed non-linear relationship between individual income and mortality RR

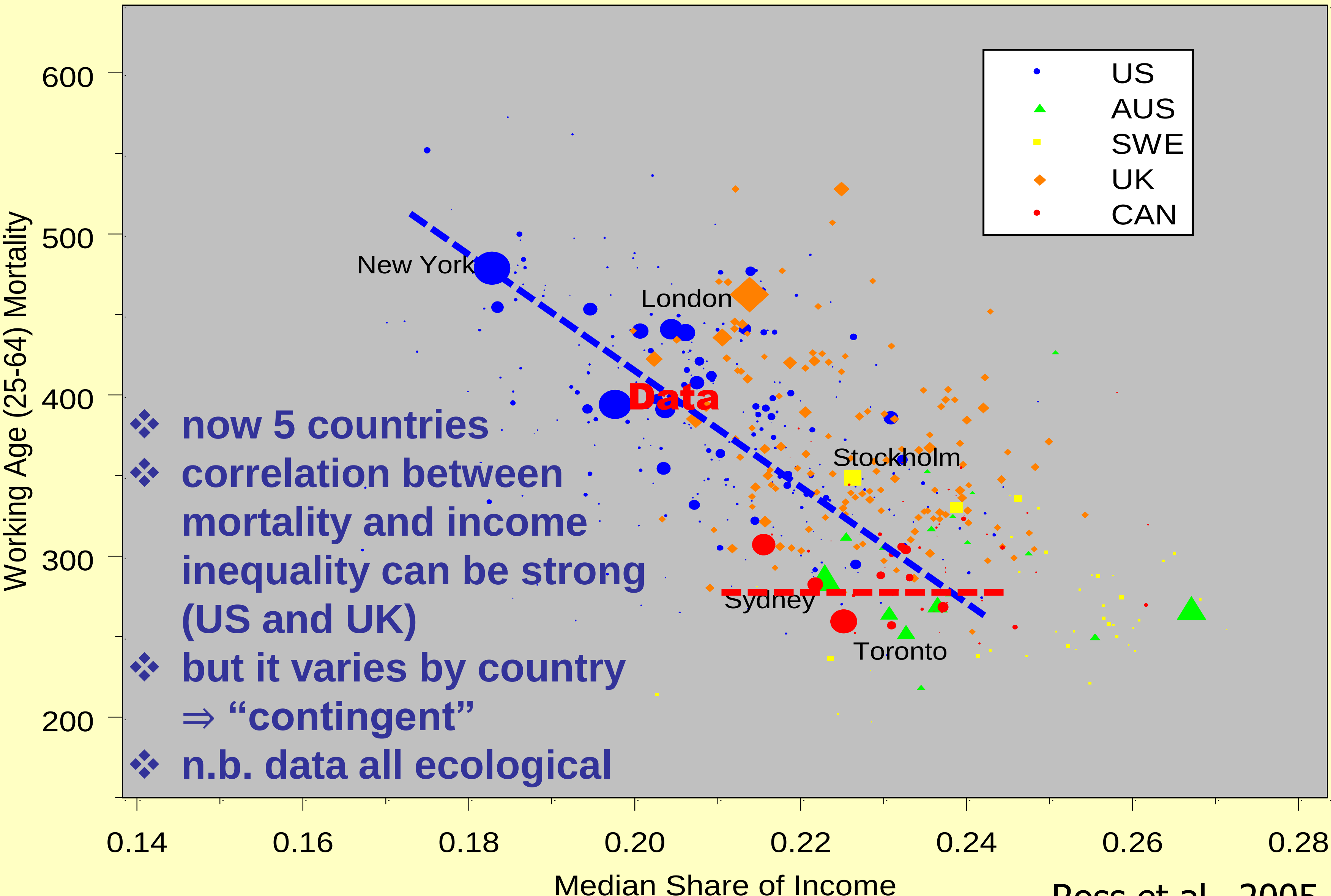
Zimmerman, 2008 (I)

“as long as there are some potential confounders that have not been or cannot be measured and included in analyses, this research endeavor will be hung over with question marks. … The literature has accordingly reached an empirical impasse. It will never be possible to adequately control for all the time-varying confounders that will be viewed as plausible, and it will never be possible to show that all potential confounders are true confounders and, therefore, to rule out the possibility that income inequality truly does affect population health.

Working Age Mortality (vertical axis) and Median Shares of Income (horizontal axis) for US and Canadian Metropolitan Areas



Income Inequality and Working-Age Mortality
528 Metropolitan Areas in Five Countries, 1990/91



- now 5 countries
- correlation between mortality and income inequality can be strong (US and UK)
- but it varies by country ⇒ "contingent"
- n.b. data all ecological

Ross et al., 2005

Empirical Impasse: No Wonder, Association is "Contingent"

Zimmerman, 2008 (II)

"…One way to resolve this problem would be to articulate a sufficiently cogent and thorough theoretical framework so that the number of potential confounders is theoretically constrained. Not only has no such framework yet been advanced, but also its absence points up an important conceptual impasse in the literature. … The literature on income inequality and health has accordingly reached a conceptual impasse to match its empirical one."

Response to Conceptual Impasse

- <u>create a theory</u> transcending typical econometric aggregation blinders, and typical neo-classical (homogeneous / average) representative agents
- <u>using ABM</u> = Agent-Based Modeling, create THIM = Theoretical Health Inequality Model

Response to Empirical Impasse

- base THIM on widely observed “stylized facts”
- where data are unavailable, make assumptions
- <u>generate testable hypotheses</u> (i.e. could be assessed if there were investments in better data and further analysis)

Simulation Models in Health Science

- growing, but still under-utilized
- unlike many other fields, e.g. astronomy
- consider how galaxies form
  - we know about gravity and relativity
  - write software to simulate motions of millions of stars
  - challenge: n-body problem cannot be solved with mathematics alone
  - stars interact (at a distance) via gravity (and “bent” space per general relativity)
  - posit a theory of galaxy evolution
  - run simulations to see if the theory fits observations

microsimulating people in societies is not rocket science or astrophysics – it's far more difficult!

“Meta Comment” on THIM Approach

- not usual epidemiological (or economic) analysis
- yes, there are risk factors and (posited) causal relationships
- but conceptualized as a “web of causality” – no single equation; rather many interacting pathways
- THIM takes a “complex systems” approach – including multiple levels, non-linear feedbacks, co-evolution of multiple state variables
- THIM is inherently multi- / trans-disciplinary – economics, demography, computer science, statistics, epidemiology, sociology, systems theory, urban geography

Understanding Health Inequalities

- starting point: observed differences in the distributions of cities by income inequality and mortality rates in Canada and the U.S. ("C" and "U" cities)
- conjecture: there is something about differences in urban structure and social forces in C and U cities [e.g. neighbourhood income segregation] that can account for these patterns
- approach: formulate a potential explanation → build a theoretical (agent-based computer simulation) model → develop "stylized facts" → establish reasonable sets of model parameters → run the model and assess conjecture

Income Inequality and Working-Age Mortality
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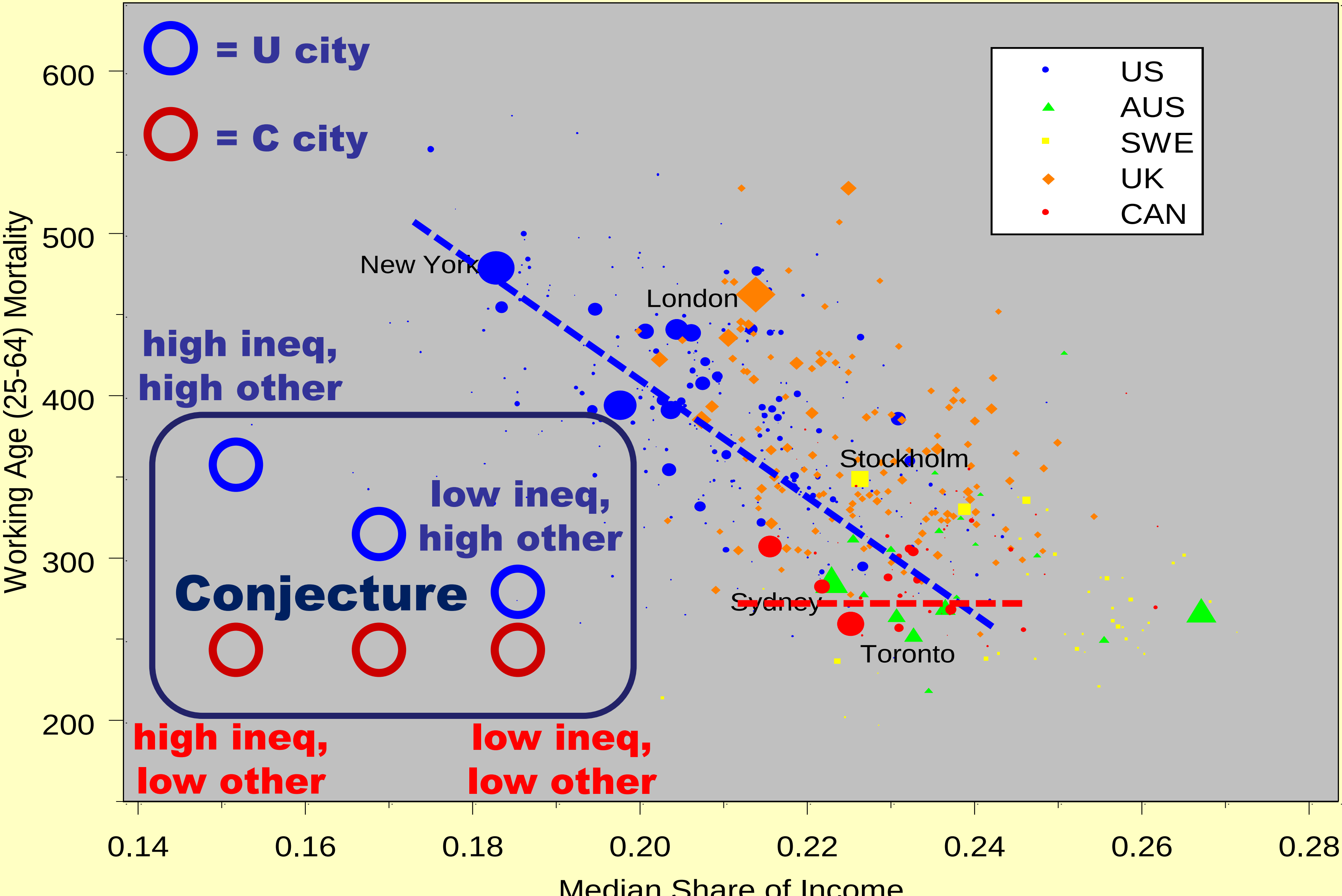


Ross et al., 2005

Formulate Explanation / Build Theory:

Main City-Level Factors to Consider

- overall level of income inequality
- neighbourhood income segregation
- parental + neighbourhood influences on children's education and subsequent incomes
- "returns to education" in terms of future income
- effects of income on health and mortality

Main Outcomes to Produce

- levels and distributions of health
- measured in terms of life expectancy (LE), and
- health-adjusted life expectancy (HALE) based on functional health status per McMaster HUI

Build Theory: Construct ABM = Agent-Based Model

- “a model is a lie that helps you see the truth”, (Howard Skipper, quoted in Mukherjee, 2010)
- “all models are wrong, but some are useful” (G Box)
- abstraction (i.e. major simplification) is essential
- but model still needs to capture main factors
  - individual <u>heterogeneity</u> in income and health
  - parental influences & life course ⇒ <u>trajectories</u>
  - neighbourhood (nbhd) factors: education as a major pathway + nbhd sorting ⇒ <u>multi-level</u>
- model should reflect “stylized facts”
- i.e. as simple as possible, but not too simple (Einstein) = “requisite complexity” (Ashby, “variety”)

Building Blocks – Main Agent Variables

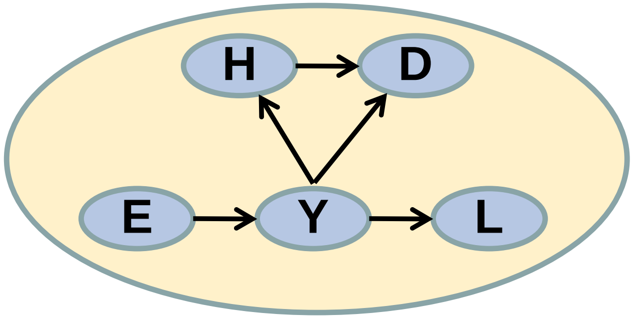
- a = age of the agent = uni-sex "sim"; max a = 100.
- time – measured in "years" (say)
- H = health status, a QALY index in the [0,1] interval.
- D = dead (Boolean, true or false).
- Y = income (dollars, non-negative).
- E = "education" measured in years, integer in [1, 20]
- L = location in a "city" comprised of many (e.g. 50) nbhds

+ Simultaneous Multiple Levels of Analysis

- individual agents
- families (parent-child dyads)
- neighbourhoods (nbhds)
- cities

THIM: Individual-Level Relationships

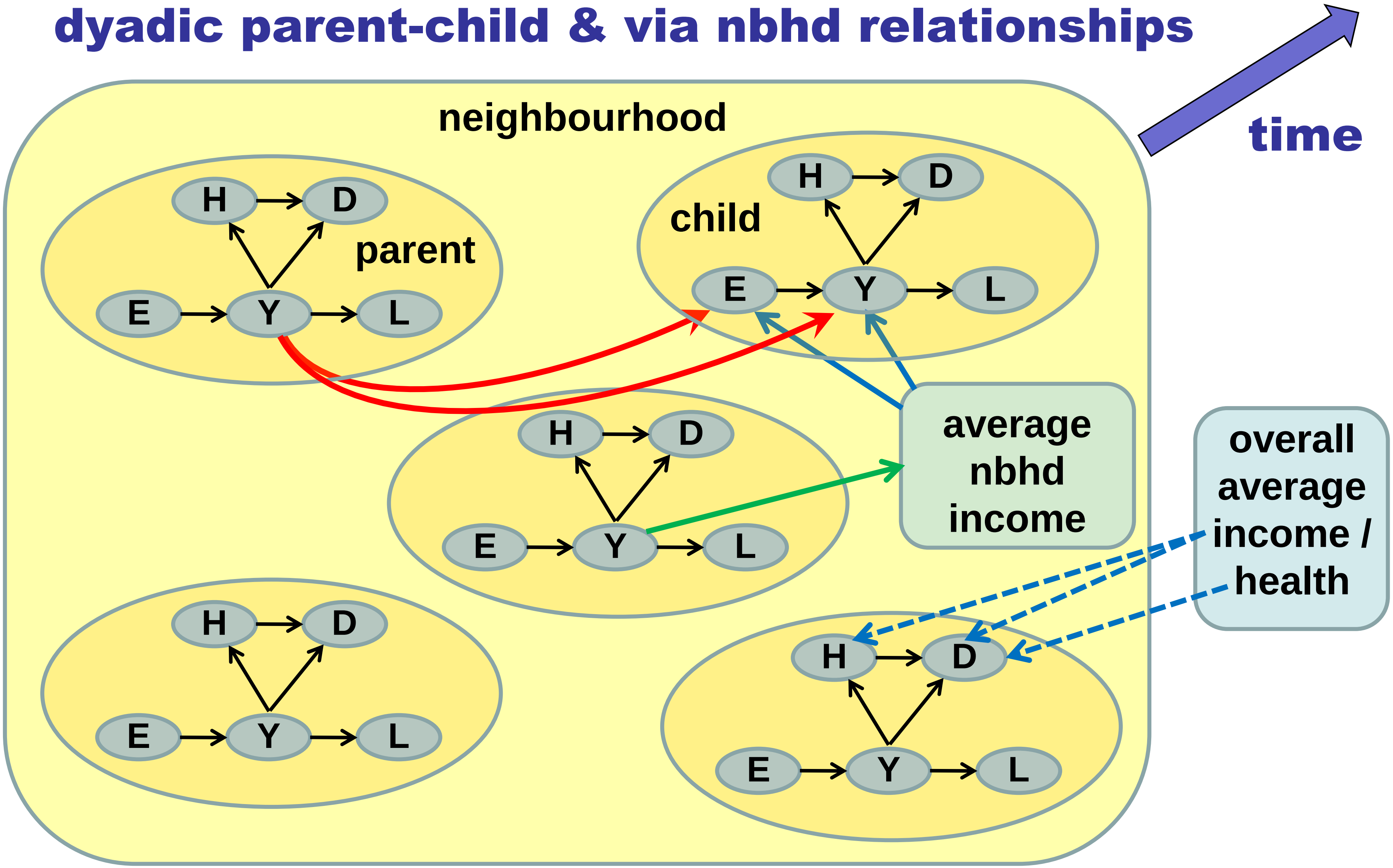
E = education
Y = income
H = health
D = death
L = location



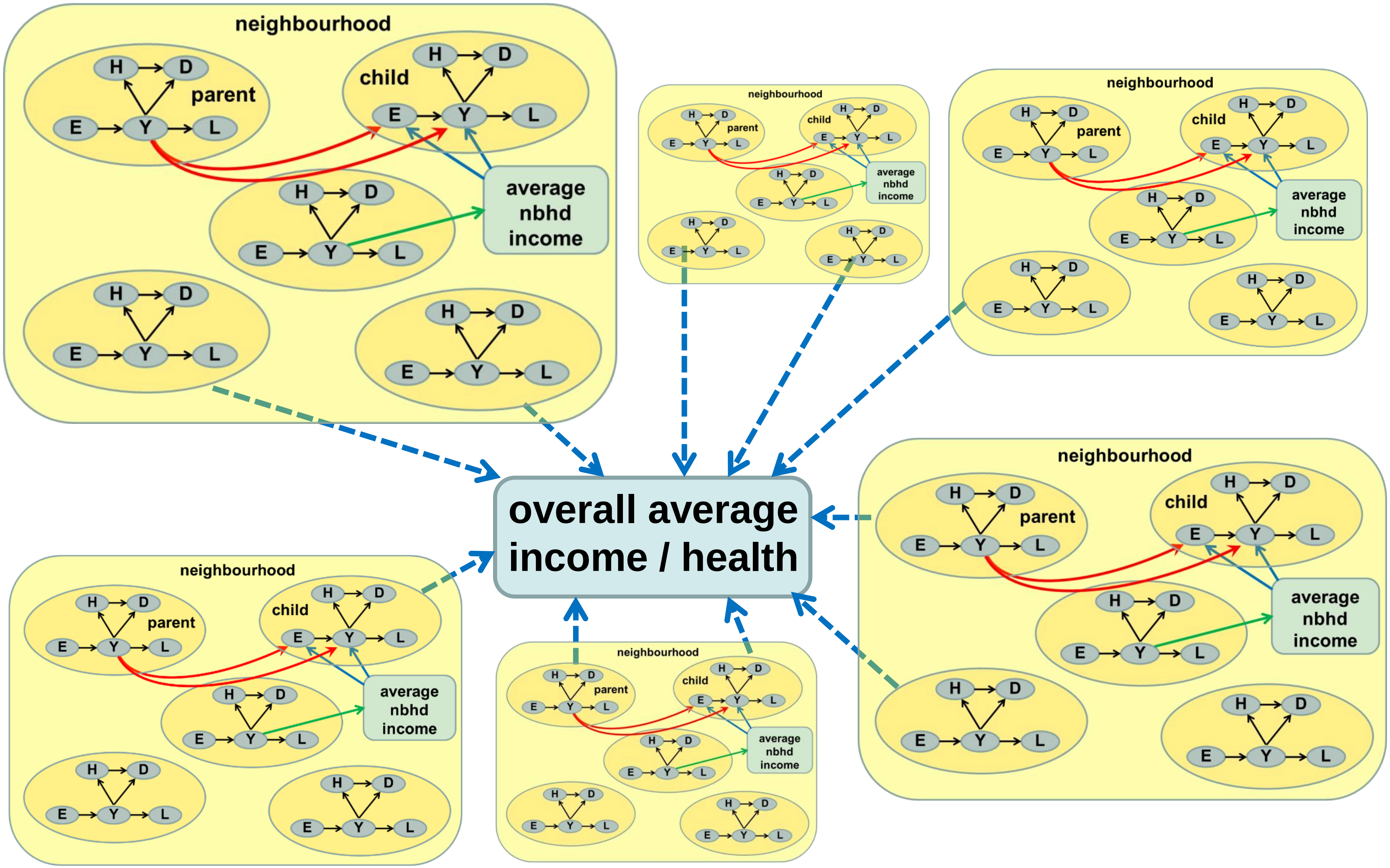
Theory: We first posit a very simple "web of causality" at the individual (unisex) "sim" level

THIM – Multi-Level Relationships

Theory: individuals (sims) also interact via dyadic parent-child & via nbhd relationships



THIM: Many Nbhds = "City"
Theory: also city-wide factors



THIM Equations

- colour = level of aggregation
- complexity arises partly due to multiple levels of aggregation

fixed at birth

- education (E) = fcn (parent's income, average nbhd income, symmetric randomness)
- potential income (Y*) = fcn (education, parent's income, average nbhd income, skewed randomness)

evolving over time / age

- income (Y_a) = average income for given age x individual's potential income (Y*) x skewed randomness
- change in health (ΔH_a) = random drift (mostly down) + fcn (own income relative to those at similar ages)
- mortality risk (D_a) = average mortality rate for given age x fcn (own income relative to those at similar ages, own health relative to the overall average)
- nbhd mobility (ΔL_a) = fcn (own income, own nbhd average income, other nbhds' average incomes)

Given Our Theory, Review Data, Build on Stylized Facts (I)

- overall levels of income inequality (U.S. higher, both overall and within most cities)
- individual-level income gradients (weak comparable data, U.S. gradient is steeper)
- age-income profile (stereotypical, assume same)
- health care expenditures (not explicitly included)
- local nbhd influences (very limited comparable data, U.S. influences are stronger)

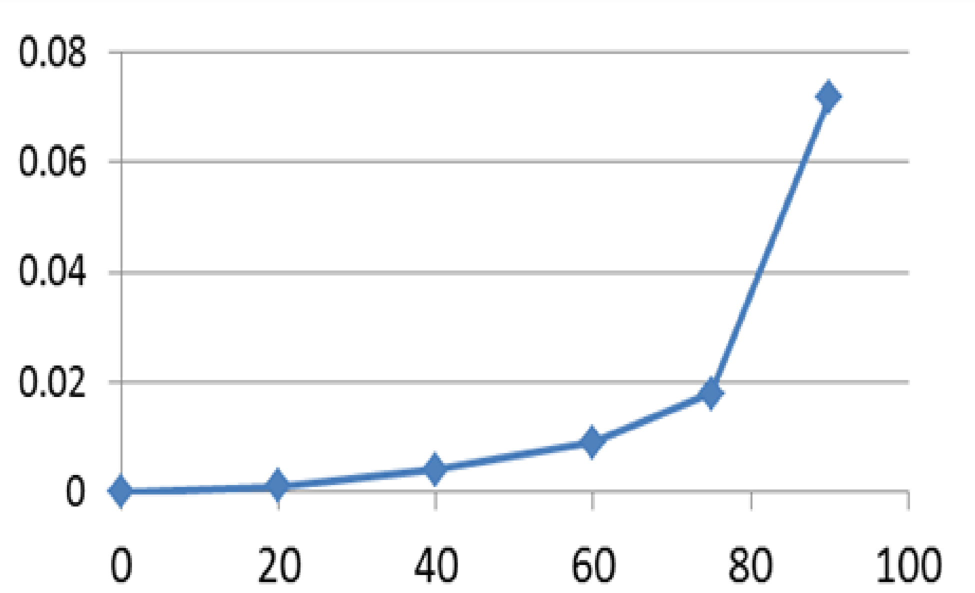
Given Our Theory, Review Data, Build on Stylized Facts (II)

- parent-to-child transmission of advantage and disadvantage – education, literacy, income (more transmission in U.S. = Corak's "Gatsby Curve" = more social stratification than Canada)
- urban governance / structure (no comparable data unfortunately)
- baseline mortality rates by age
- residual / otherwise unexplained inequality in potential income (Y*) (no data, hypothesize)

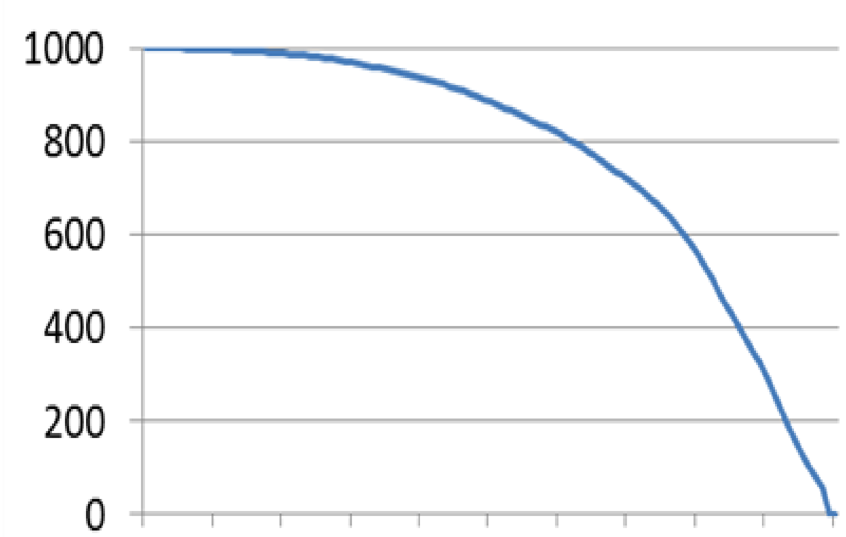
Simplified Stereotypical Age-Income Profile (assumed identical for U and C cities)

note: THIM is OK with non-parametric inputs

Baseline (a) Age-Specific Mortality Rates (vertical axis) and (b) Corresponding Population Surviving (radix = 1,000; vertical axis), both by Age (horizontal axes) (assumed identical for U and C cities)

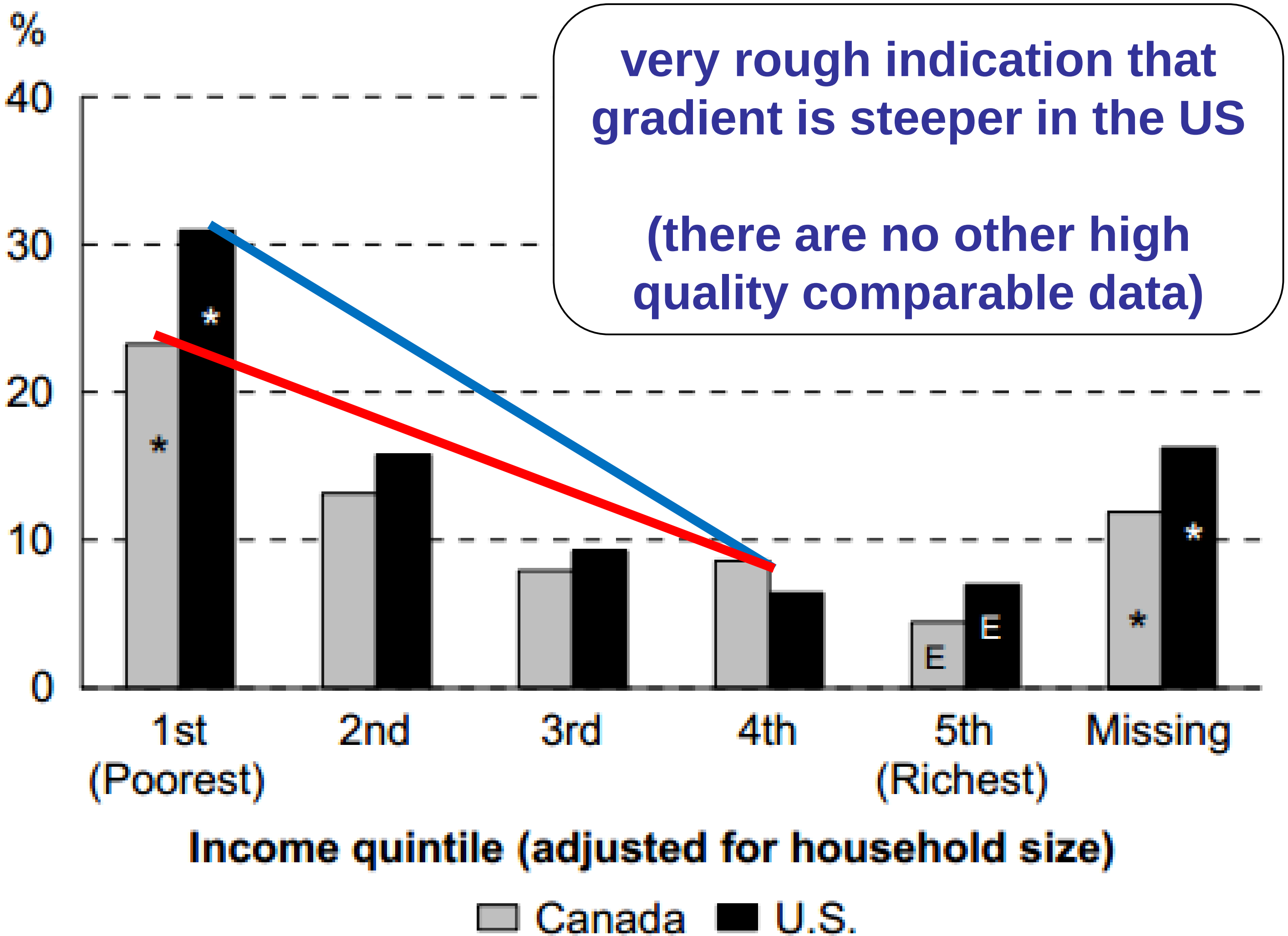


a. Mortality Rates by Age



b. Survival by Age

Fair/poor general health by household income quintile, Canada and United States, 2002/03‡

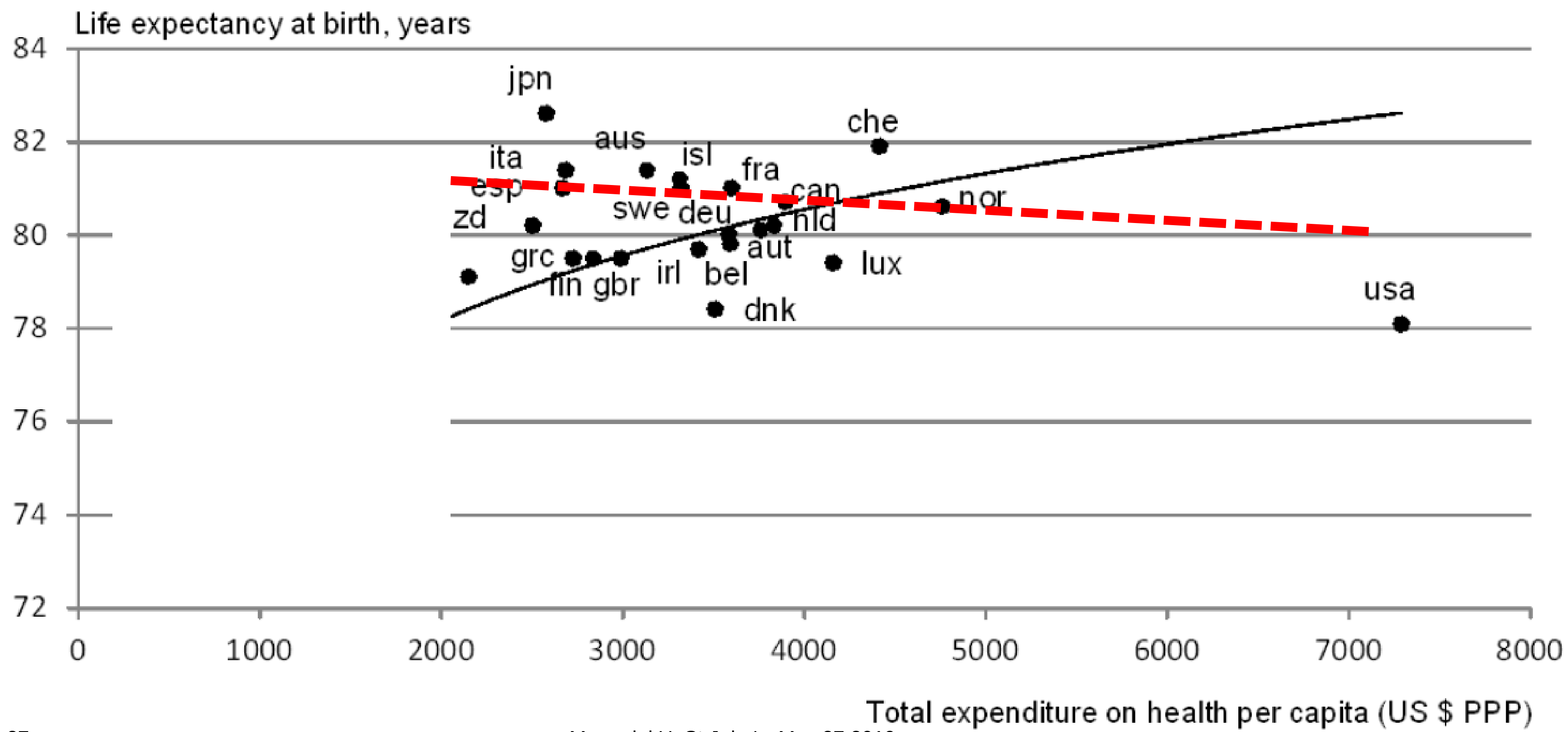


Data source: *Joint Canada/United States Survey of Health, 2002/03.*
Notes: *Household population aged 18 and over.*

OECD 2010 – Health Care Expenditure Per Capita versus Life Expectancy

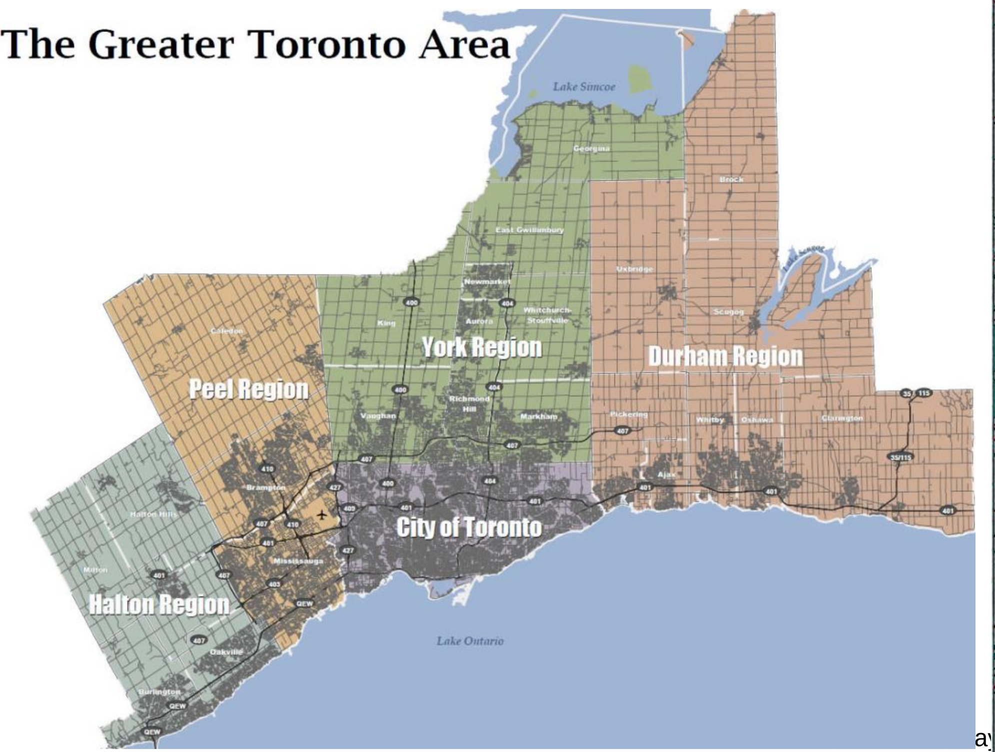
Health Care (input) $ ≠ Health

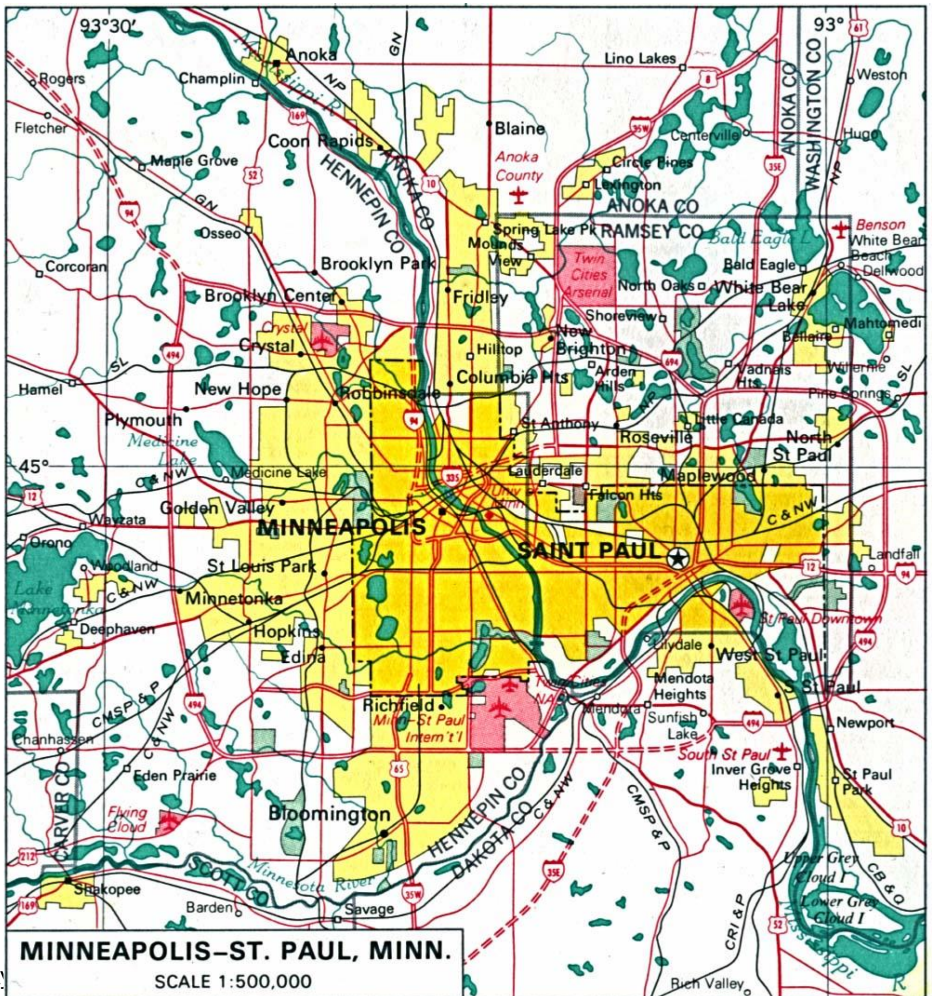
Joumard, I., C. André and C. Nicq (2010), "Health Care Systems: Efficiency and Institutions", *OECD Economics Department Working Papers*, No. 769, OECD Publishing. doi: 10.1787/5kmfp51f5f9t-en



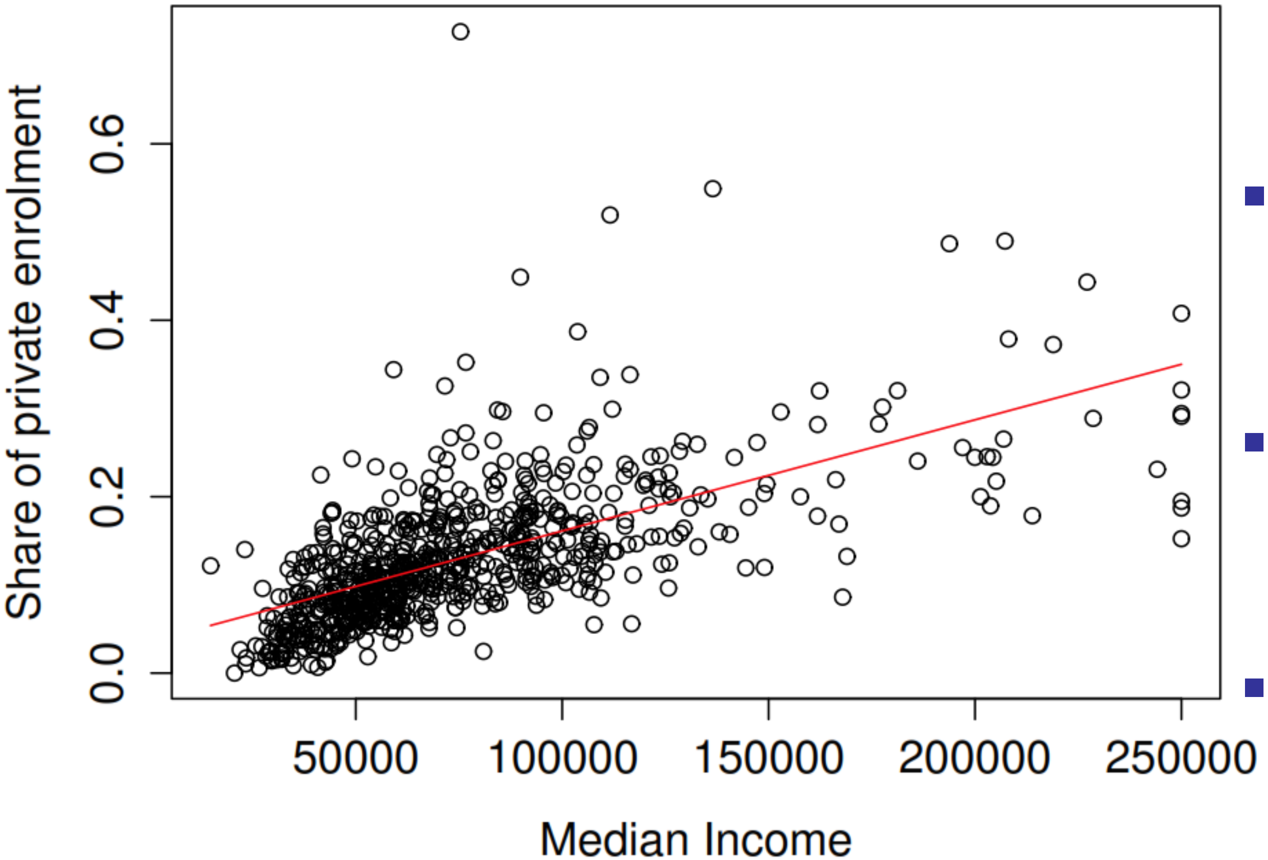
City Structure: e.g. Minneapolis and Toronto

- 200+ versus ~15 elected governments (municipal, school boards, etc.)?
- comparable data lacking





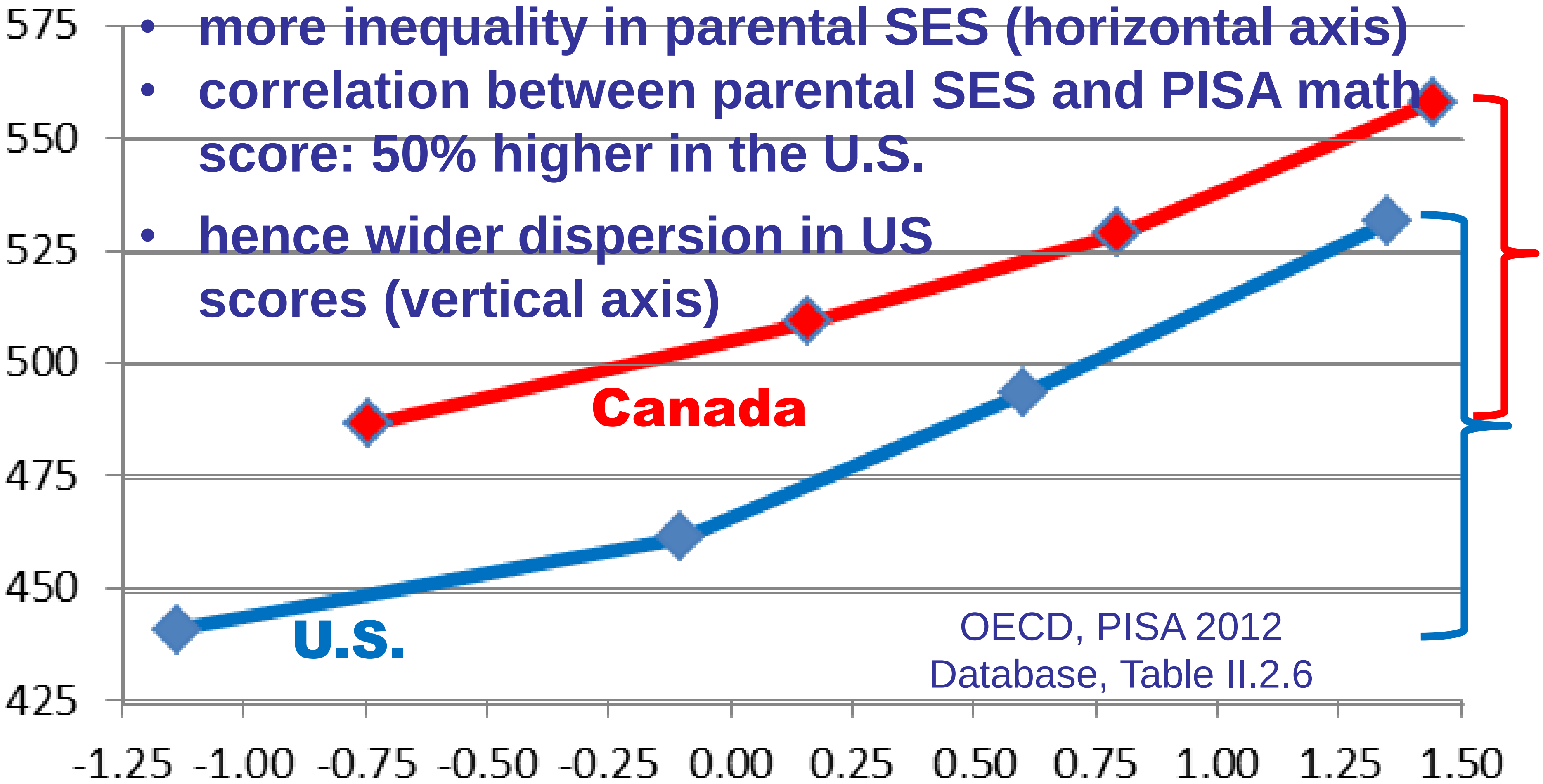
Share of Private School Enrolment and Median Income Across 772 School Districts in California, 2012



- compare: 38 school districts in Ontario (2x school boards)
- equivalent to ~ 100 school districts across Canada
- compare 772 districts in CA (similar population)
- hence ~1/8th as many school districts per capita

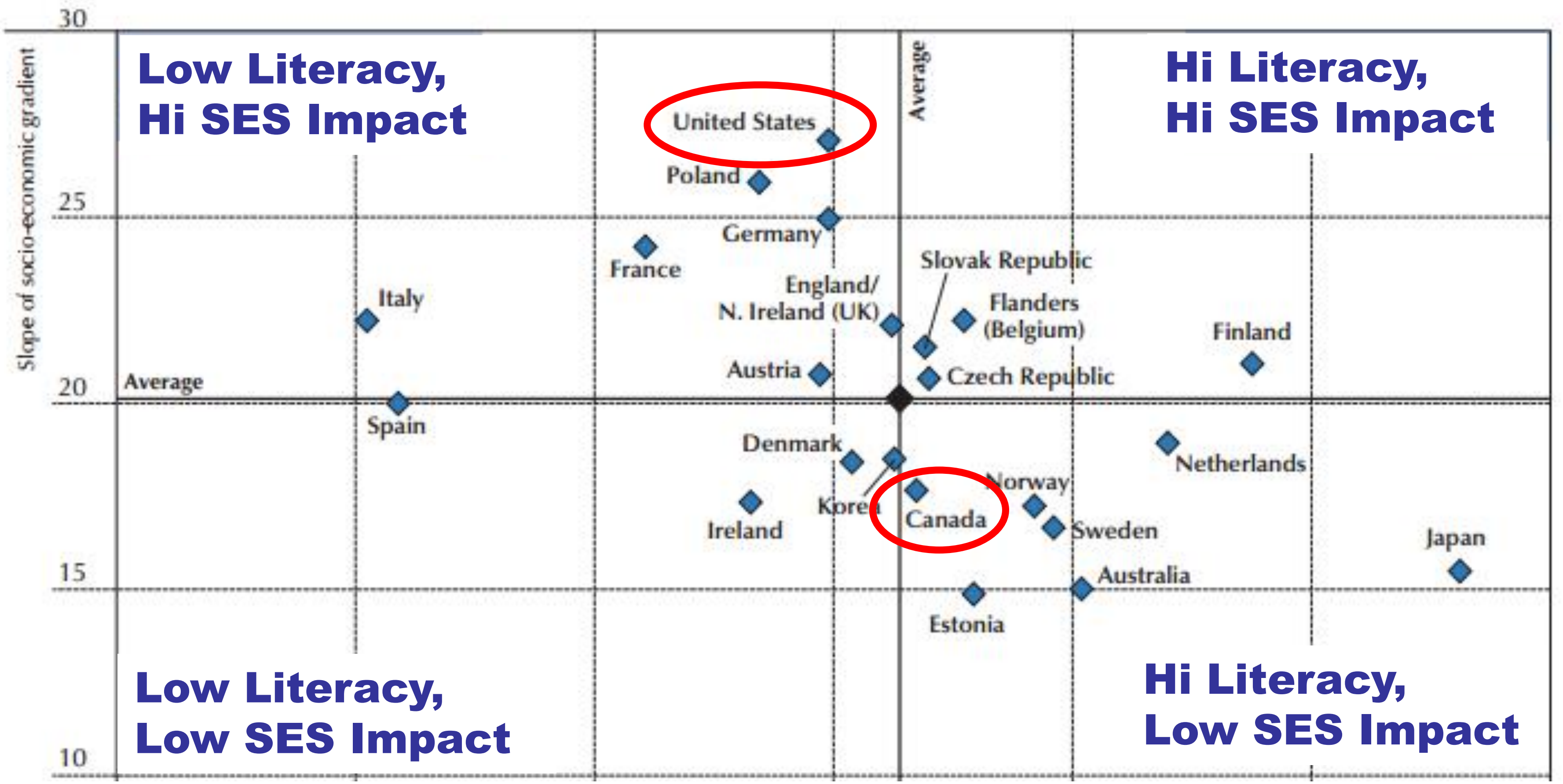
Parental Influence – PISA Math Scores by Parental Socio-Economic Status (SES) Quartiles, OECD 2013

- Canadian math scores higher overall than U.S
- more inequality in parental SES (horizontal axis)
- correlation between parental SES and PISA math score: 50% higher in the U.S.
- hence wider dispersion in US scores (vertical axis)



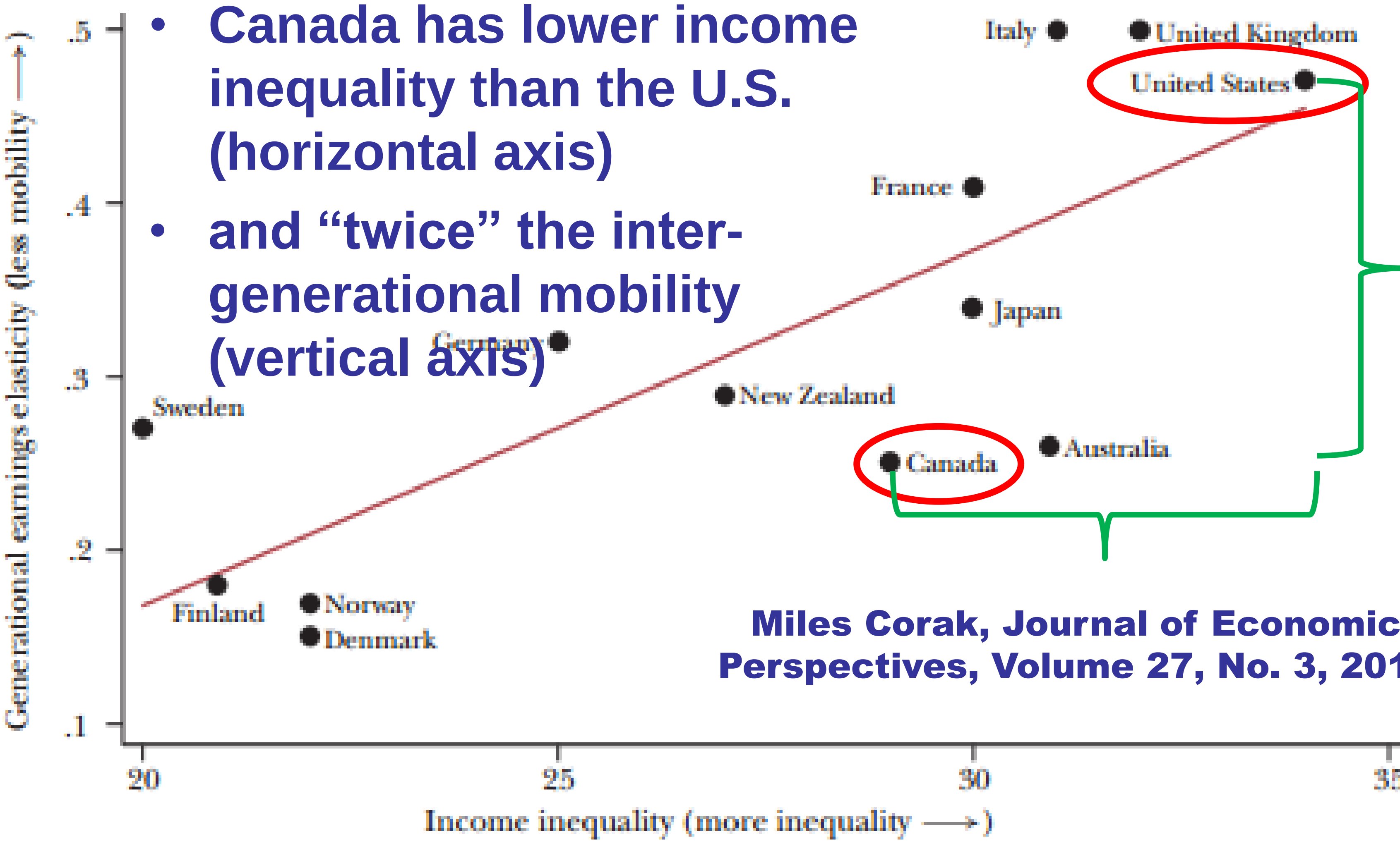
Parental Influence – Adult Literacy Score by Slope of Parental SES Gradient

(OECD Skills Outlook 2013 Figure 3.8c)



Parental Influence – Father-Son Income Elasticities vs Gini

The Great Gatsby Curve: More Inequality is Associated with Less Mobility across the Generations

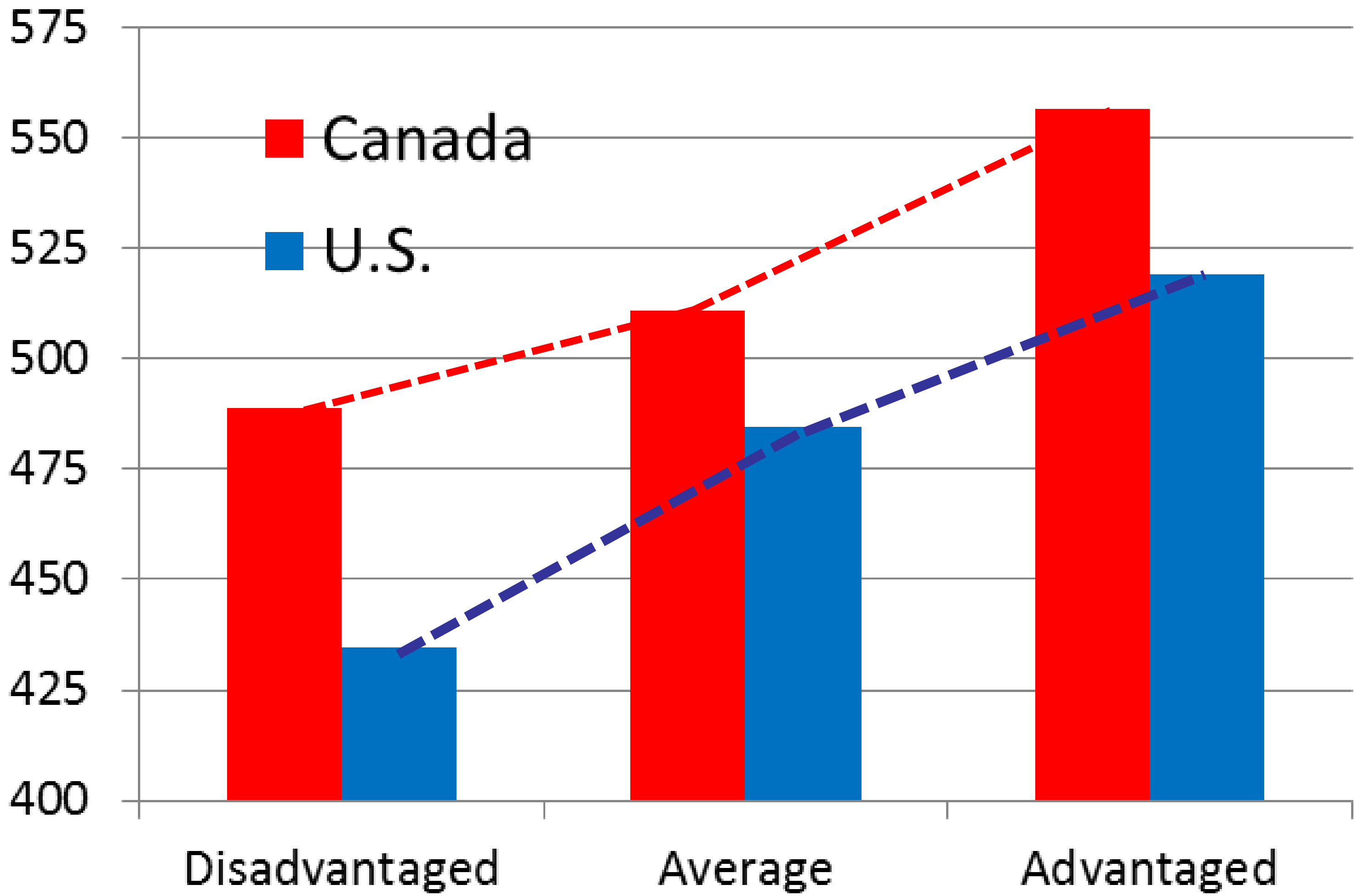


- Canada has lower income inequality than the U.S. (horizontal axis)
- and "twice" the inter-generational mobility (vertical axis)

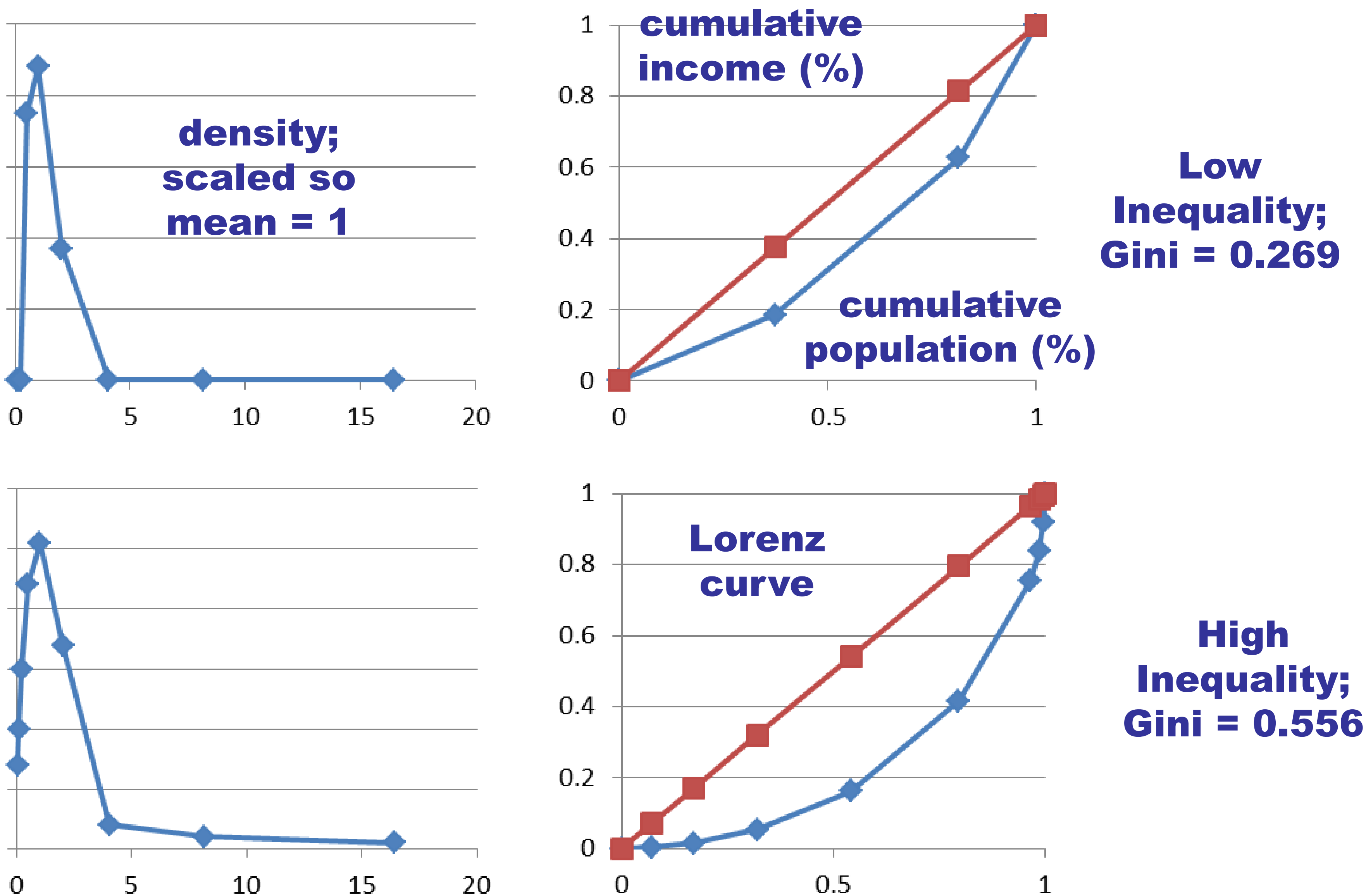
Miles Corak, Journal of Economic Perspectives, Volume 27, No. 3, 2013

“Neighbourhood” Influence – PISA Math Scores by Average School SES

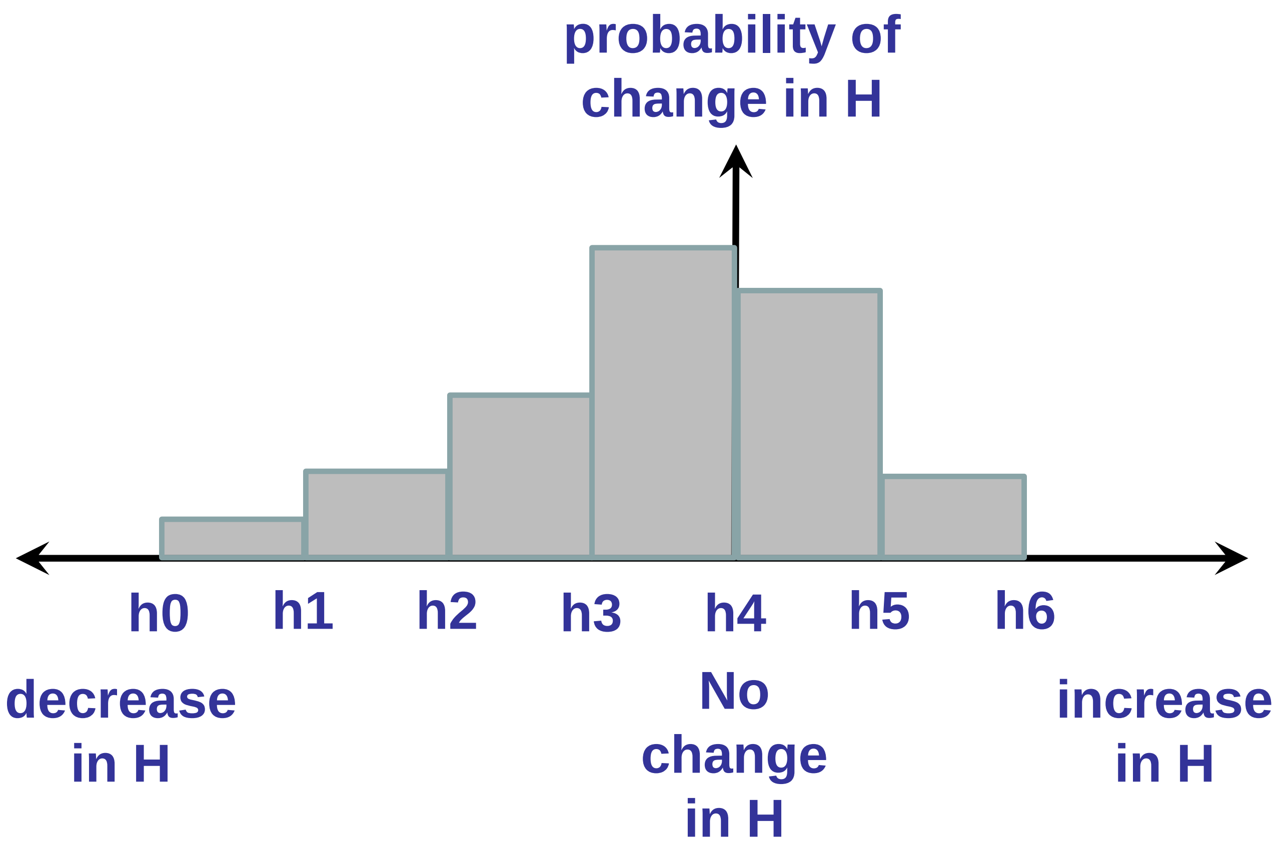
OECD, PISA 2012 Database, Table II.2.10



Input Parameters – High and Low Inequality "Potential (Y*) Income" Distributions

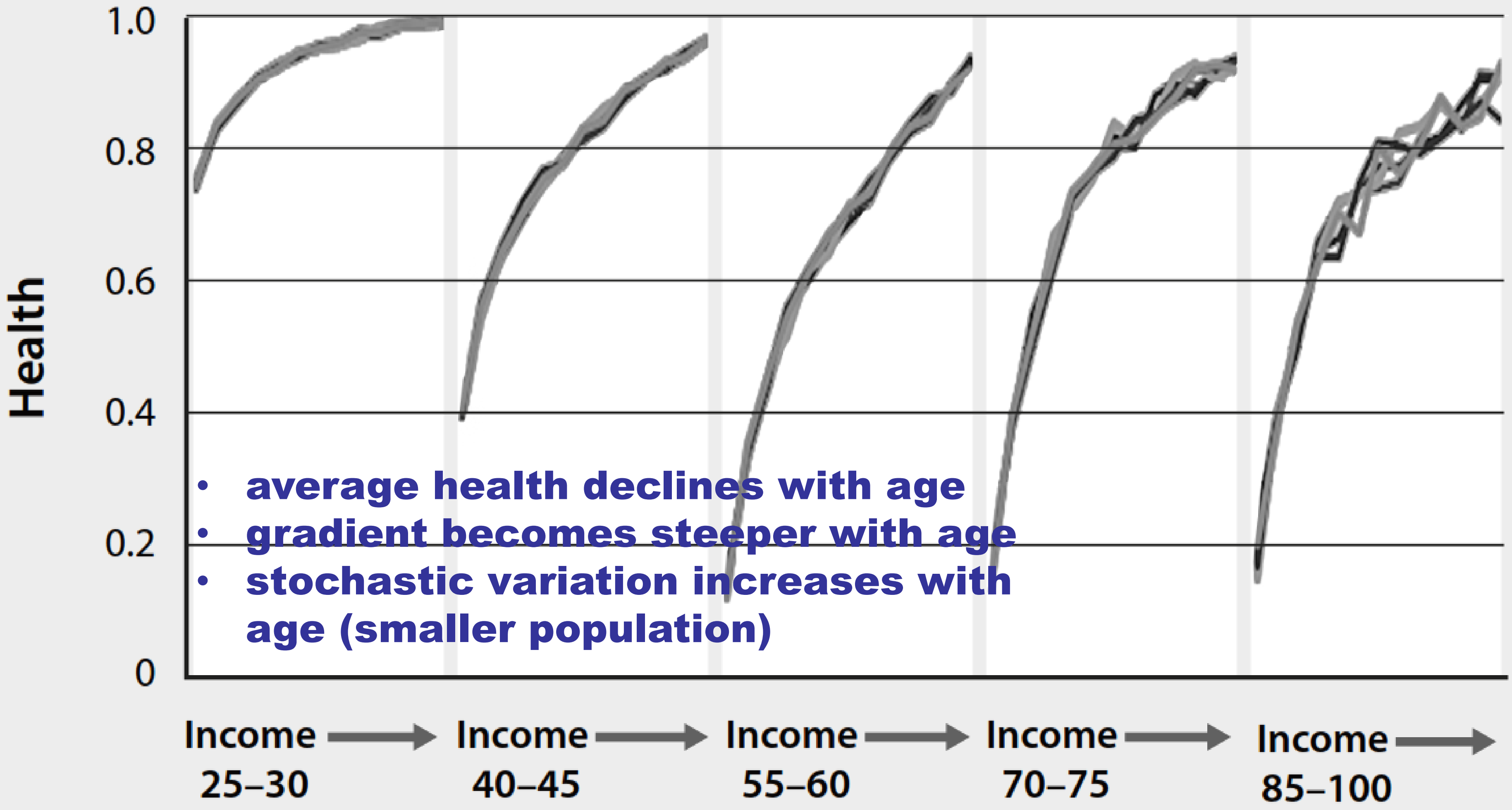


Hypothetical Distribution for Health Change Random Walk



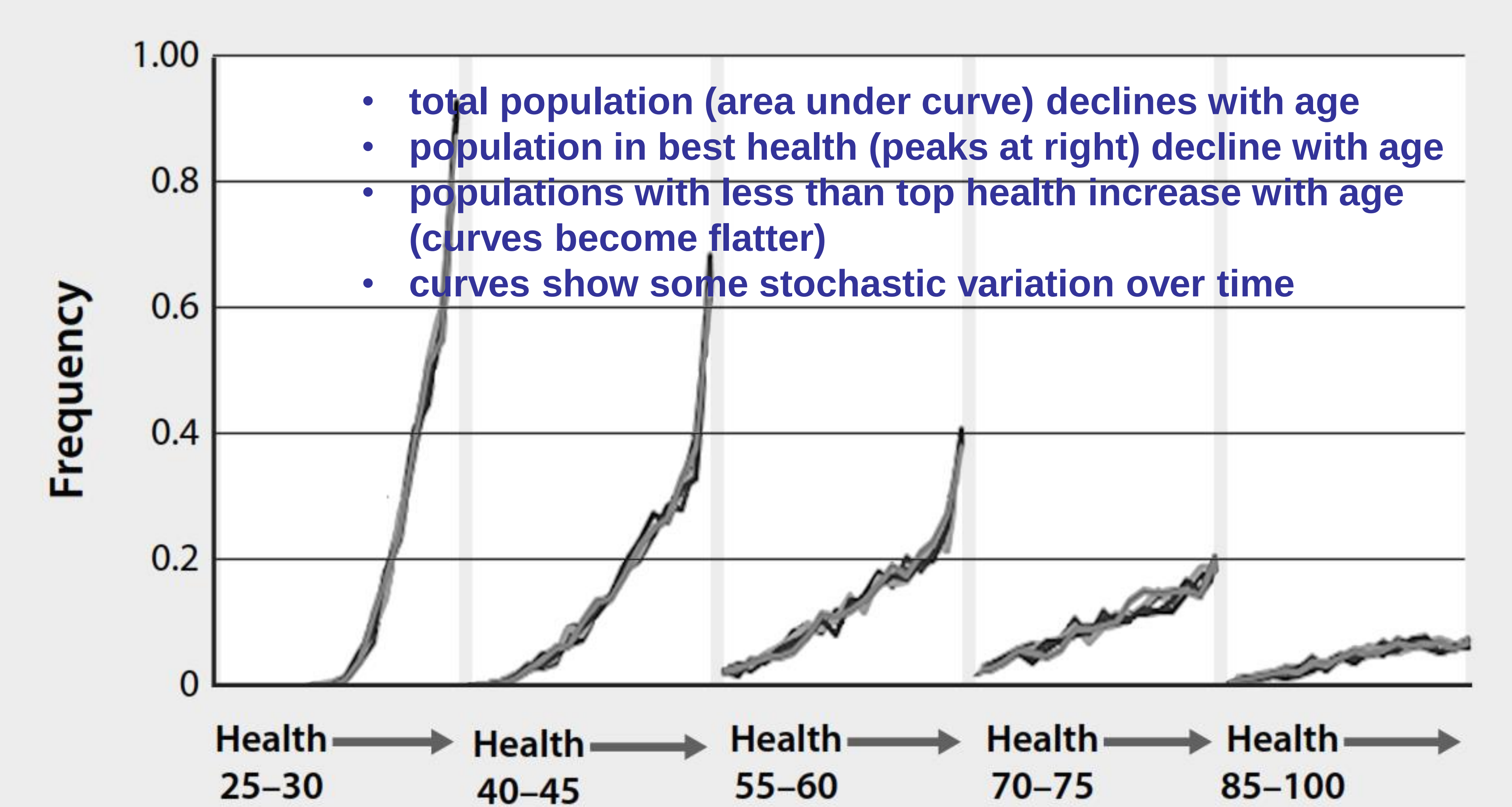
Given Stylized Facts, and Given Posited Structure of THIM, Can We Generate Plausible Outputs (via Computer Simulation, Recall Galaxy Collisions)?

Simulated Health Status (H) Distributions by Income for Selected Age Groups (averaged over multiple "decades")



- average health declines with age
- gradient becomes steeper with age
- stochastic variation increases with age (smaller population)

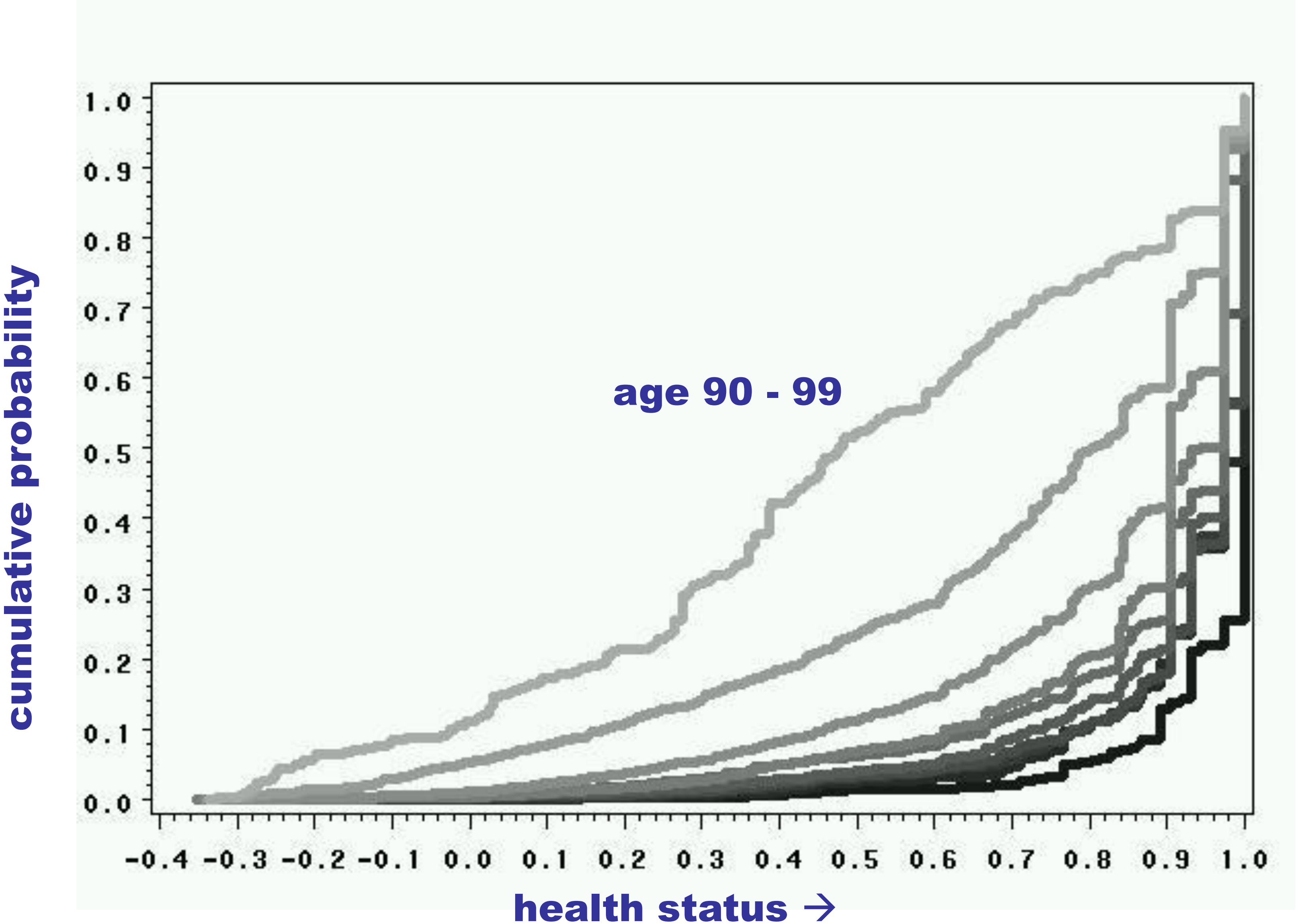
Simulated Cumulative Health Status (H) Distributions for Selected Age Groups (averaged over multiple "decades")



- total population (area under curve) declines with age
- population in best health (peaks at right) decline with age
- populations with less than top health increase with age (curves become flatter)
- curves show some stochastic variation over time

Observation: NPHS HUI Distributions by Age Group

(ordered youngest (black) to oldest (gray))



Given Stylized Facts, and Posited Theory, and Plausible Outputs of Intermediate Variables (e.g. Distribution of H by Age and Income)

Three Experiments

1. can we reproduce observed contingent correlations for U and C cities?
2. how important is neighbourhood sorting?
3. what are the most important factors accounting for the U and C city differences?

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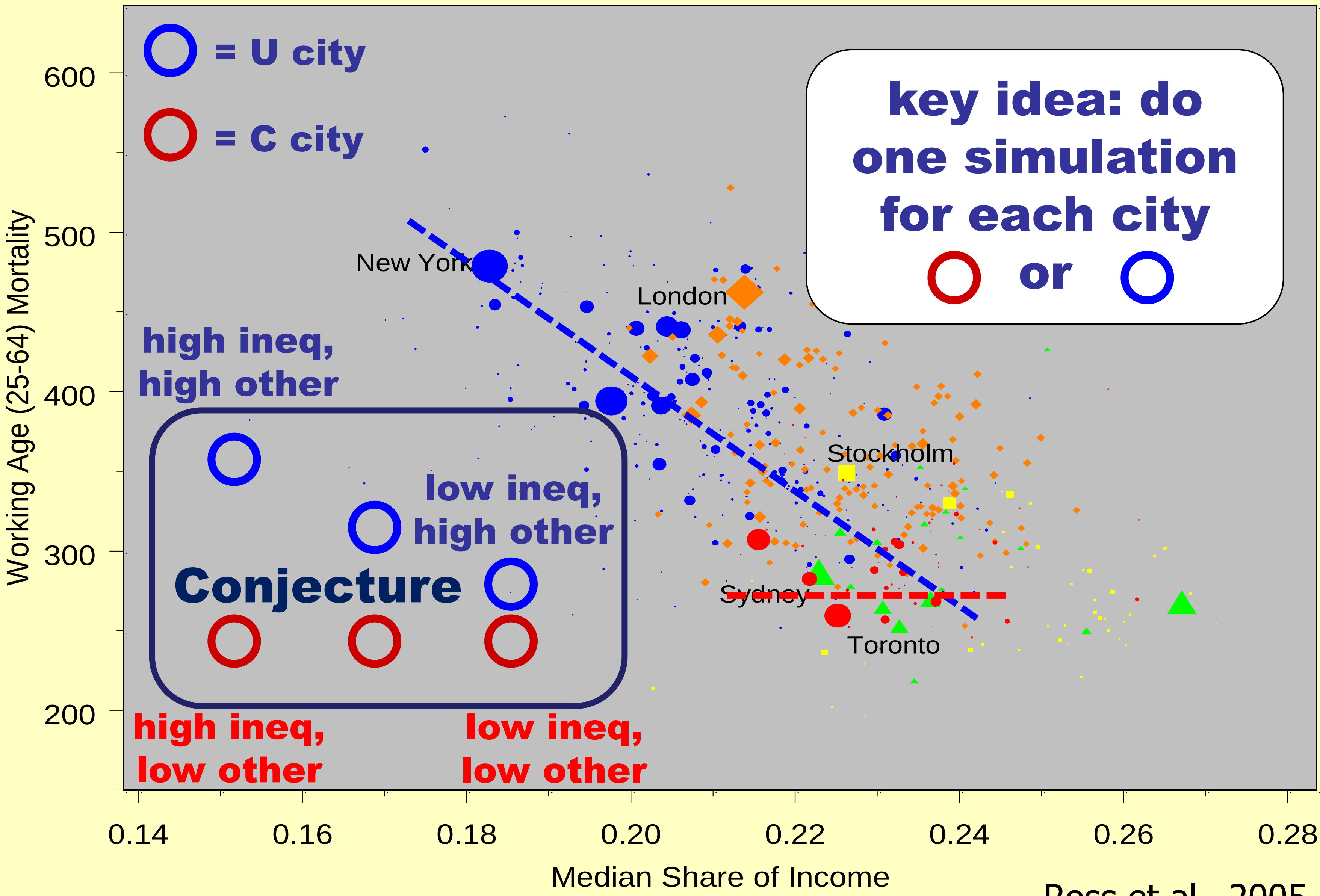

Ross et al., 2005

THIM Simulation Factors at Play (I)

- **nbhd income sorting (L)**
  - higher income threshold (+ or -) before sim “wants” to change nbhds
  - ⇒ lower propensity to move when income changes
  - ⇒ more heterogeneous nbhds by income
  - = higher within nbhd inequality, lower between
- **education (E)**
  - lower variability around mean = more equal schooling outcomes
  - weaker correlations with parental and mean nbhd income = less transmission of parental (dis)advantage

THIM Simulation Factors at Play (II)

- **income (Y)**
  - lower correlations with education, parental income, mean nbhd income = less influence of socio-economic status environment
  - more year-to-year variability
- **health (H)**: weaker effect of own income on ΔH
- **death (D)**: weaker effects of own health and own income on mortality

Parameters for Five C and U Scenarios

	C	U	U**	C*	U*
Education (E) – std dev (years)	2	4	4	**3**	**3**
E-lasticity – parent's income	1	2	[illegible]	[illegible]	[illegible]
E-lasticity – nbhd mean income	0.5	1	[illegible]	[illegible]	[illegible]
Y-lasticity – education	0.2	0.6	[illegible]	[illegible]	[illegible]
Y-lasticity – parent's income	0.2	0.6	[illegible]	[illegible]	[illegible]
Y-lasticity – nbhd mean income	0.2	1	[illegible]	[illegible]	[illegible]
Y – annual lognormal std dev	0.05	0.15	[illegible]	[illegible]	[illegible]
H – effect of income on ΔH	0.001	0.006	[illegible]	[illegible]	[illegible]
D – effect on H on mortality	0.25	0.75	0.75	**0.3**	**0.3**
D – effect of Y on mortality	0.08	0.24	0.24	**0.1**	**0.1**
number of nbhds	3	12	**3**	3	12
proportional Y diff for moving	0.75	0.15	**0.75**	0.75	0.15
proportional Y diff for moving	0.95	0.25	**0.95**	0.95	0.25

focus on relative differences, not specific levels

base case parameters have been selected to produce plausible results

Parameters for Five C and U Scenarios

	C	U	U**	C*	U*
Education (E) – std dev (years)	2	4	4	**3**	**3**
E-lasticity – parent's income	1	2			
E-lasticity – nbhd mean income	0.5	1			
Y-lasticity – education	0.2	0.6			
Y-lasticity – parent's income	0.2	0.6			
Y-lasticity – nbhd mean income	0.2	1			
Y – annual lognormal std dev	0.05	0.15			
H – effect of income on ΔH	0.001	0.006			
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D – effect of Y on mortality	0.08	0.24			
number of nbhds	3	12	**3**	3	12
proportional Y diff for moving	0.75	0.15	**0.75**	0.75	0.15
proportional Y diff for moving	0.95	0.25	**0.95**	0.95	0.25

base case U and C scenarios = 1st experiment

can we reproduce observed contingent correlations?

parameters reflect U versus C stylized facts

Parameters for Five C and U Scenarios

	C	U	U**	C*	U*
Education (E) – std dev (years)	2	4	4	**3**	**3**
E-lasticity –	1	2	2	**1.2**	**1.8**
E-lasticity -	0.5	1	1	**0.6**	**0.9**
Y-lasticity -	0.2	0.6	0.6	**0.2**	**0.5**
Y-lasticity -	0.2	0.6	0.6	**0.2**	**0.5**
Y-lasticity -	0.2	1	1	**0.4**	1
Y – annual	0.05	0.15	0.15	**0.1**	**0.1**
H – effect	0.001	0.006	0.006	**0.008**	**0.008**
D – effect	0.25	0.75	0.75	**0.3**	**0.3**
D – effect of Y on mortality	0.08	0.24	0.24	**0.1**	**0.1**
number of nbhds	3	12	**3**	3	12
proportional Y diff for moving	0.75	0.15	**0.75**	0.75	0.15
proportional Y diff for moving	0.95	0.25	**0.95**	0.95	0.25

what about nbhd sorting = 2nd experiment;

can it account for observed Canada – US difference?

give to US Canadian nbhd parameters; no change to others

Parameters for Five C and U Scenarios

	C	U	U**	C*	U*
Education (E) …)	2	4	4	3	3
E-lasticity – pa…	1	2	2	1.2	1.8
E-lasticity – n… ne	0.5	1	1	0.6	0.9
Y-lasticity – e…	0.2	0.6	0.6	0.2	0.5
Y-lasticity – pa…	0.2	0.6	0.6	0.2	0.5
Y-lasticity – n… ne	0.2	1	1	0.4	1
Y – annual log…	0.05	0.15	0.15	0.1	0.1
H – effect of i…	0.001	0.006	0.006	0.008	0.008
D – effect on…	0.25	0.75	0.75	0.3	0.3
D – effect of Y…	0.08	0.24	0.24	0.1	0.1
number of nbh…	3	12	**3**	3	12
proportional Y diff for moving	0.75	0.15	**0.75**	0.75	0.15
proportional Y diff for moving	0.95	0.25	**0.95**	0.95	0.25

alternatively, what about the other factors = 3rd experiment;

can they account for observed Canada – US difference?

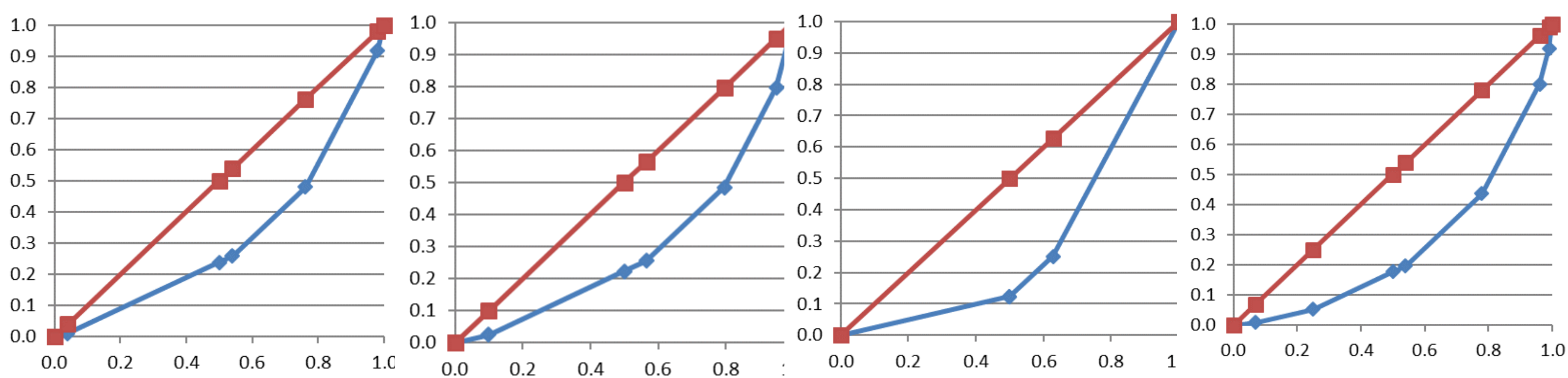
try weakening C versus U differences

Income "Inequality" Measures for Y* Inputs and for Y Outputs

Y* Gini	0.093	0.269	0.358	0.408	0.425	0.471	0.556	0.571
Y* median share	0.450	0.314	0.238	0.223	0.123	0.177	0.127	0.098
Y* polarization	0.015	0.206	0.330	0.291	0.657	0.350	0.380	0.467

Y* is the input distribution of relative potential income (mean = 1, positively skewed, non-negative)

eight alternative distributions have been (perversely) specified – rank orders of inequality indicators vary(!)



Income “Inequality” Measures for Y* Inputs and for Y Outputs

Y* Gini	0.093	0.269	0.358	0.408	[illegible]	0.471	0.556	0.571
Y* median share	0.45[illegible]	[illegible]	[illegible]238	0.223	[illegible]	0.177	0.127	0.098
Y* polarization	0.01[illegible]	[illegible]	[illegible]330	0.291	0.657	0.350	0.380	0.467
C Gini	0.281	0.383	0.441	0.477	0.403	0.496	0.511	0.530
C median share	0.298	0.233	0.187	0.174	0.202	0.165	0.160	0.152
C polarization	0.140	0.190	0.266	0.270	0.247	0.280	0.276	0.287
U Gini	0.393	0.409	0.416	0.420	0.420	0.467	0.514	0.474
U median share	0.225	0.213	0.208	0.206	0.206	0.178	0.155	0.179
U polarization	0.192	0.213	0.219	0.221	0.221	0.259	[illegible]	[illegible]

U more ineq

C more pol

C more med

U more eq

Y* = input distribution of relative potential income

Y = resulting income distribution after simulations of U and C cities

Y inequality indicators move in complicated ways given Y*

- **Y* → Y dis-equalizing at low inequality, and vice versa**
- **C cities sometimes more equalizing than U cities, sometimes not**

Parameters for Five C and U Scenarios

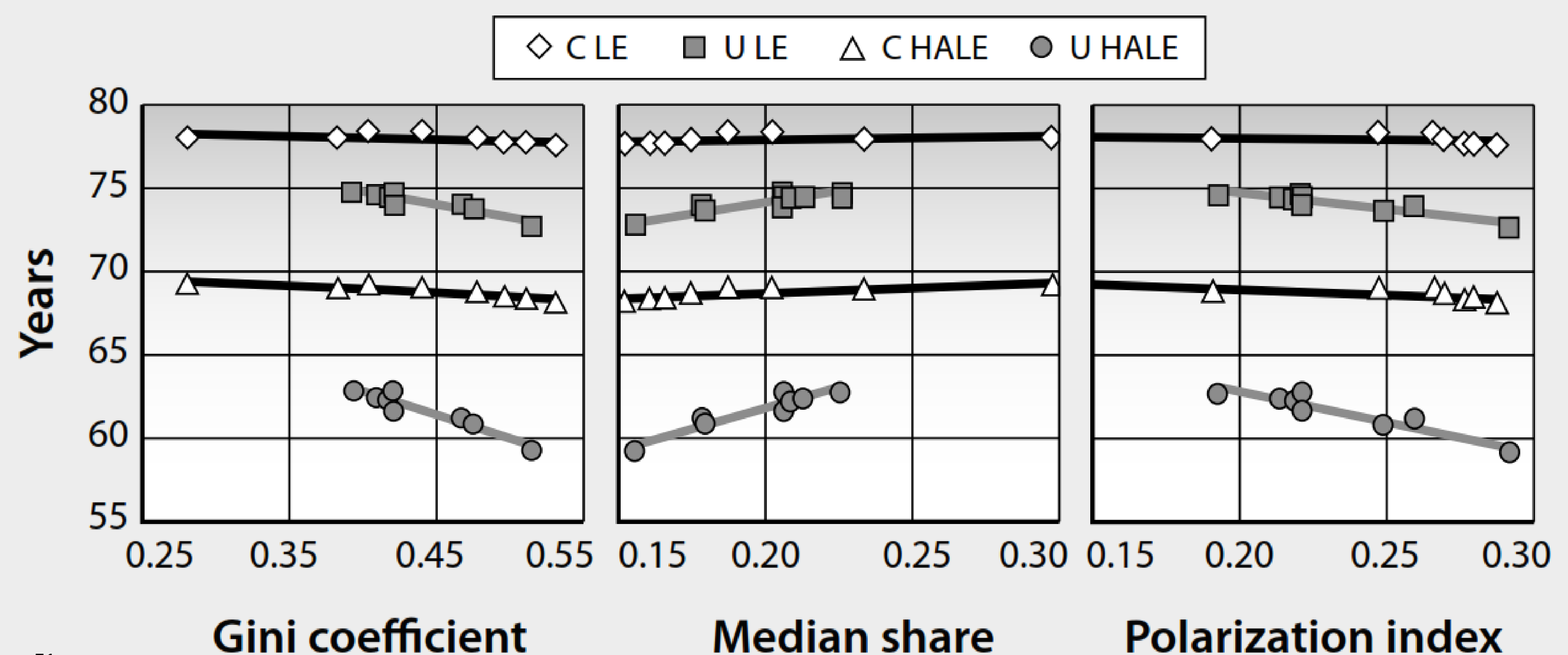
	C	U	U**	C*	U*
Education (E) – std dev (years)	2	4	4	**3**	**3**
E-lasticity – parent's income	1	2	[illegible]	[illegible]	**1.8**
E-lasticity – nbhd mean income	0.5	1	[illegible]	[illegible]	**.9**
Y-lasticity – education	0.2	0.6	[illegible]	[illegible]	**.5**
Y-lasticity – parent's income	0.2	0.6	[illegible]	[illegible]	**.5**
Y-lasticity – nbhd mean income	0.2	1	[illegible]	[illegible]	1
Y – annual lognormal std dev	0.05	0.15	[illegible]	[illegible]	**.1**
H – effect of income on ΔH	0.001	0.006	0.006	**0.008**	**0.008**
D – effect on H on mortality	0.25	0.75	0.75	**0.3**	**0.3**
D – effect of Y on mortality	0.08	0.24	0.24	**0.1**	**0.1**
number of nbhds	3	12	**3**	3	12
proportional Y diff for moving	0.75	0.15	**0.75**	0.75	0.15
proportional Y diff for moving	0.95	0.25	**0.95**	0.95	0.25

base case scenarios

can we reproduce observed contingent correlations?

Result 1 – THIM Can Reproduce Observed Contingent Correlation Patterns

- **C cities have higher LE and higher HALE than U cities**
- **C cities have very little slope**
- **U cities have considerable slope**
- **U city slope is steeper for HALE than LE**



Parameters for Five C and U Scenarios

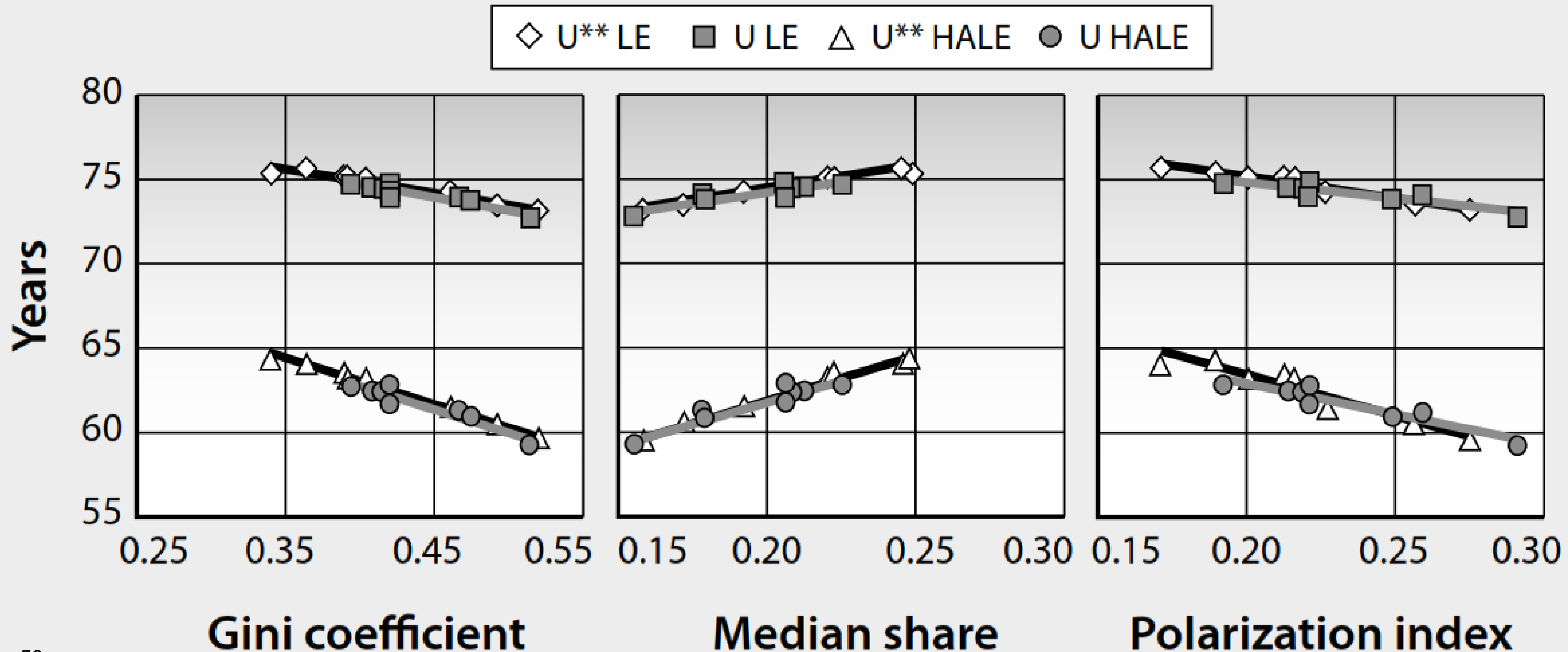
	C	U	U**	C*	U*
Education (E) – std dev (years)	2	4	4	**3**	**3**
E-lasticity – parent's income	1	2	2	**1.2**	**1.8**
E-lasticity – nbhd mean income	0.5	1			**0.9**
Y-lasticity – education	0.2	0.6			**0.5**
Y-lasticity – parent's income	0.2	0.6			**0.5**
Y-lasticity – nbhd mean income	0.2	1			1
Y – annual lognormal std dev	0.05	0.15			**0.1**
H – effect of income on ΔH	0.001	0.006			**008**
D – effect on H on mortality	0.25	0.75	0.75	**0.3**	**0.3**
D – effect of Y on mortality	0.08	0.24	0.24	**0.1**	**0.1**
number of nbhds	3	12	**3**	3	12
proportional Y diff for moving	0.75	0.15	**0.75**	0.75	0.15
proportional Y diff for moving	0.95	0.25	**0.95**	0.95	0.25

what about nbhd sorting

can it account for observed Canada – US difference?

Result 2 – “Segregation” = Weaker nbhd Sorting Does NOT Account for Observed Contingent Correlation

- compared to U cities,
- fewer “gates and ghettos” in U** cities
- U** cities more equal (i.e. more to L / R / L)
- U** cities have higher LE and HALE
- but no significant change in slope



Parameters for Five C and U Scenarios

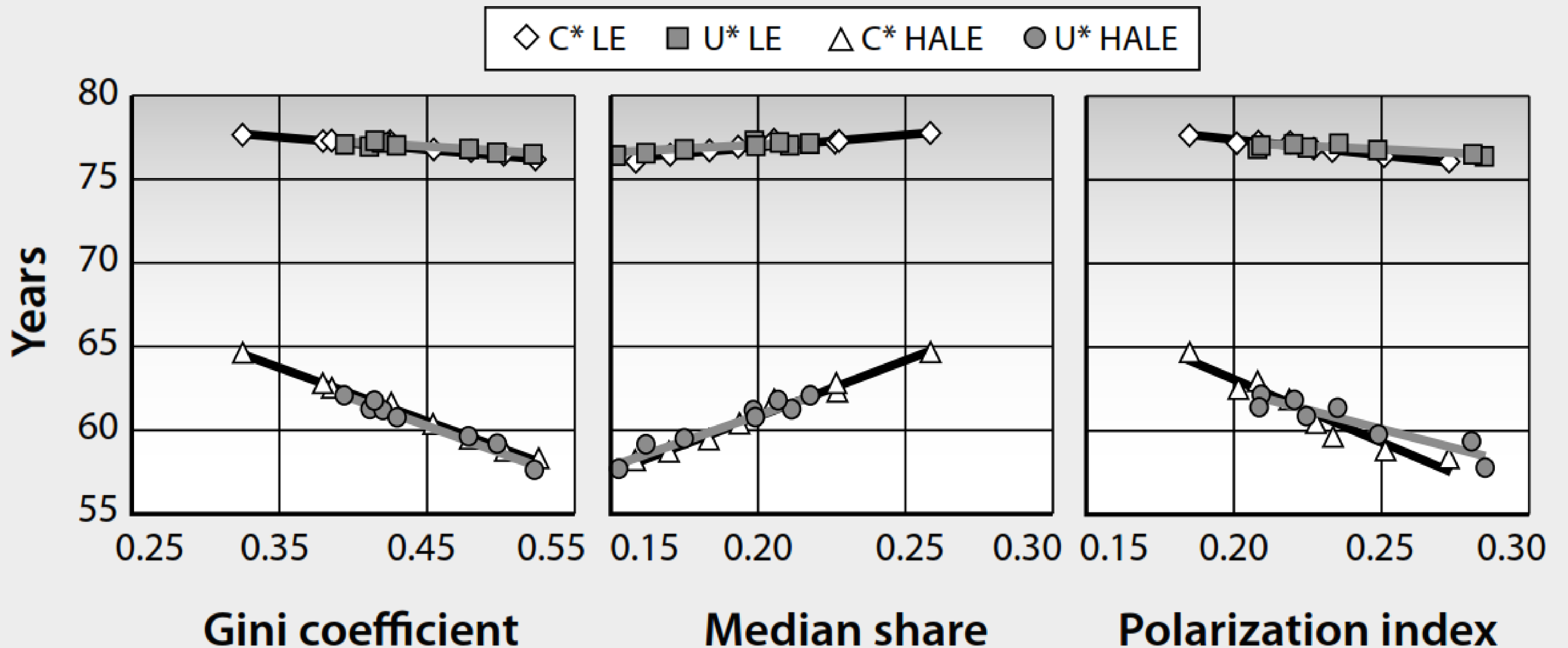
	C	U	U**	C*	U*
Education (E) – std dev (years)	2	4	4	3	3
E-lasticity – parent's income	1	2	2	1.2	1.8
E-lasticity – nbhd mean income	[illegible]	[illegible]	1	0.6	0.9
Y-lasticity – education	[illegible]	[illegible]	.6	0.2	0.5
Y-lasticity – parent's income	[illegible]	[illegible]	.6	0.2	0.5
Y-lasticity – nbhd mean income	[illegible]	[illegible]	1	0.4	1
Y – annual lognormal std dev	[illegible]	[illegible]	15	0.1	0.1
H – effect of income on ΔH	[illegible]	[illegible]	06	0.008	0.008
D – effect on H on mortality	[illegible]	[illegible]	.75	0.3	0.3
D – effect of Y on mortality	0.08	0.24	0.24	0.1	0.1
number of nbhds	3	12	**3**	3	12
proportional Y diff for moving	0.75	0.15	**0.75**	0.75	0.15
proportional Y diff for moving	0.95	0.25	**0.95**	0.95	0.25

alternatively, what about the other factors?

can they account for observed Canada – US difference?

Result 3 – What if U and C Cities had More Similar Non-Nbhd Factors?

- C and U cities now essentially same slopes
- C cities still more equal (i.e. more to L / R / L)
- more similar non-nbhd factors ⇒ failure to reproduce observed contingency of correlation
- ⇒ Gatsby curve & local public goods (including education) likely much more important



Concluding Comments – Methods

- success! we have constructed a (n.b. not the only possible) theory to account for observed contingent correlation of income inequality and population health
- this theory is testable – e.g. with better and more comparable Canada-US data
- the contingent correlations observed at the outset support Zimmerman’s claim of an “empirical impasse” – but only when standard statistical / econometric methods are used
- we have constructed a worked example that resolves Zimmerman’s “conceptual impasse”, and sheds new light on his “empirical impasse”

Concluding Comments – Substance

- THIM provides an acceptable theory accounting for ("explaining") observed contingent correlation
- two hypotheses have then been explored
- *not*: nbhd sorting / income segregation
- *yes*: other factors that are stronger in the US
  - effects of income on health and mortality
  - parent to child transmission of income and education (dis)advantage
  - effect of nbhd income on education
- thus a "hidden gem" of Canadian <u>*public health*</u> policy: municipal and school board amalgamation
  - ⇒ more equitable distribution of local public goods