Measuring Inequality with Ordinal data

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Winter School

January 2015

Outline

Introduction

- Ordinal data issue widespread in inequality analysis
- Many applications proceed just as though cardinal:
  - life satisfaction / inequality of happiness: Oswald and Wu (2011), Stevenson and Wolfers (2008b), Yang (2008)
  - health status: Van Doorslaer and Jones (2003)
- Small literature that takes ordinal problem seriously
  - early approaches using 1st order dominance, the median
  - Abul Naga and Yalcin (2008,2010), Allison and Foster (2004), Zheng (2011)
  - but these have limitations
- Present approach based on Cowell and Flachaire (2014)

Income Inequality

- 3 ingredients:
  - **"income":** family income, earnings, wealth $x \in X \subseteq \mathbb{R}$.
  - **"income-receiving unit":** n persons
  - **method of aggregation:** function $X^n \to \mathbb{R}$
- Usually work with $X^n_\mu \subset \mathbb{R}$
- X^n_μ: Distributions obtainable from a given total income $n\mu$ using lump-sum transfers
- Obviously can't do that here: μ is undefined

Utility

Cardinalisation and inequality

- 3 ingredients:
  - **"income":** $u = U(x)$.
  - **"income-receiving unit":** n persons (as before)
  - **method of aggregation:** function $\mathbb{U}^n \to \mathbb{R}$
- Problem of cardinalisation
- But just assuming cardinal utility is no use
  - Already pointed out in Atkinson (1970)
  - Dalton (1920) suggested inequality of (cardinal) utility
  - But if, for all i, you multiply u_i by $\lambda \in (0,1)$ and add $\delta = \mu[1-\lambda]$...
  - ...this will automatically reduce measured inequality.
- Is this just a technicality?
- Can we proceed just as with regular income?

Categorical variable

Example: Access to Services

	Case 1	Case 2
	n_k	n_k
Both Gas and Electricity	25	0
Electricity only	25	50
Gas only	25	50
Neither	25	0

- Suppose we have no information about needs / usage
- It seems clear that Case 1 is more unequal than Case 2

Example self-reported health

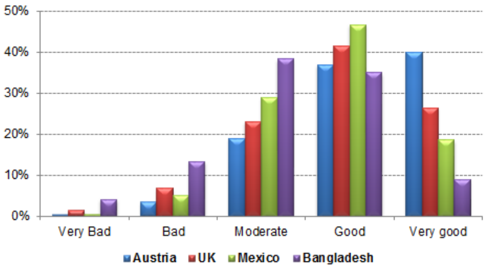
- World Health Survey (WHS)
  - a general population survey
  - developed by WHO
- Question: Health State Descriptions
  - overall health
  - including both physical and mental health
- In general, how would you rate your health today?
  - Very good
  - Good
  - Moderate
  - Bad
  - Very Bad
- Compare distributions across countries

SRH Results: four countries

	Austria	**UK**	**Mexico**	**Bangladesh**
	number of responses			
Very good	423	318	7193	494
Good	390	498	18112	1949
Moderate	200	278	11221	2132
Bad	36	82	2002	741
Very bad	4	17	218	228

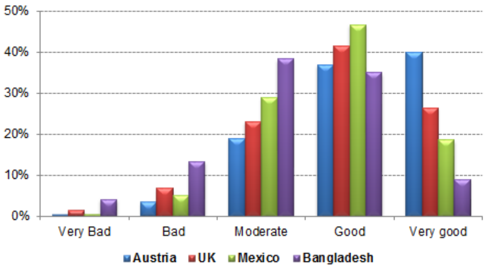
- For all countries: rank categories in order
- For each country: compute freq distributions across categories
- How to evaluate inequality?

SRH Inequality: Gini



	At	UK	Mx	BD	
(1,2,3,4,5)	0.111	0.130	0.116	0.154	(BD,UK,Mx,At)
(1,2,3,4,1000)	0.593	0.725	0.800	0.884	(BD,Mx,UK,At)
(-1000,2,3,4,5)	0.608	0.821	0.856	2.377	(BD,Mx,UK,At)

SRH Inequality: Coeff of Variation



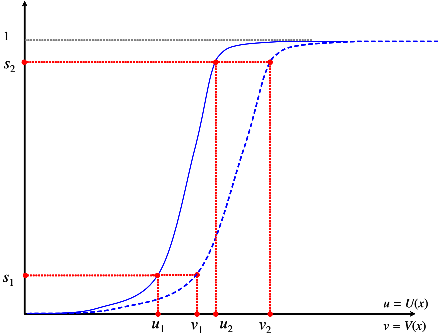
	At	UK	Mx	BD	
(1,2,3,4,5)	0.209	0.244	0.219	0.287	(BD,UK,Mx,At)
(1,2,3,4,1000)	1.210	1.638	2.056	3.088	(BD,Mx,UK,At)
(-1000,2,3,4,5)	187.5	11.43	40.45	5.264	(At,Mx,UK,BD)

Status and Information

- Step 1 is to define status
  - depends on the purpose of inequality analysis
  - depends on structure of information
  - conventional inequality approach only works in narrowly defined information structure
- In some cases a person's status is self-defining
  - income
  - wealth
- In some cases defined given additional distribution-free information
  - example: if it is known that utility is $\log(x)$
- In some cases requires information on distribution
  - GRE, TOEFL
  - "opportunity" (de Barros et al. 2008)

Status and Distribution (1)

- i's status uniquely defined for a given distribution of u



- disposes of the problem of cardinalisation
  - U and $V = \varphi(U)$ two cardinalisations of the utility of x
  - for each i:u_i and v_i map into s_i

Status and distribution (2)

- This approach works for categorical data
  - we just have an ordered arrangement of categories $1, 2, ..., k, ..., K$
  - and the numbers in each category $n_1, n_2, ..., n_k, ..., n_K$
- Merger principle
  - merge two adjacent categories that are irrelevant for i
  - then this should leave i's status unaltered
- Merger principle implies that s should be additive in the n_k
  - upward-looking status: $\sum_{\ell=1}^{k(i)} n_\ell$
  - downward-looking status: $\sum_{\ell=k(i)}^{K} n_\ell$
  - see also Yitzhaki (1979)

Elements of the Model

- Individual's status is given by $s \in S \subseteq \mathbb{R}$
  - status determined from utility?
- Vector of status in a population of size n : $\mathbf{s} \in S^n$
- $e \in S$: an equality-reference point
  - could be specified exogenously
  - could also depend on status vector $e = \eta(\mathbf{s})$
  - η need not be increasing in each component of $\mathbf{s}$
- Inequality: aggregate distance from e
  - don't need an explicit distance function
  - implicitly define through inequality ordering $\succeq$

Basic Axioms

- **[Continuity]** $\succeq$ is continuous on S^n
- **[Monotonicity]** If $\mathbf{s}, \mathbf{s}' \in S_e^n$ differ only in their ith component then (a) if $s_i' \geq e$:$s_i > s_i' \Longleftrightarrow \mathbf{s} \succ \mathbf{s}'$; (b) if $s_i' \leq e$: $s_i' > s_i \Longleftrightarrow \mathbf{s} \succ \mathbf{s}'$
- **[Independence]** For $\mathbf{s}, \mathbf{s}' \in S_e^n$, if $\mathbf{s} \sim \mathbf{s}'$ and $s_i = s_i'$ for some i then $\mathbf{s}(\varsigma, i) \sim \mathbf{s}'(\varsigma, i)$ for all $\varsigma \in [s_{i-1}, s_{i+1}] \cap \left[s_{i-1}', s_{i+1}'\right]$
- **[Anonymity]** For all $\mathbf{s} \in S^n$ and permutation matrix $\mathbf{P}$, $\mathbf{Ps} \sim \mathbf{s}$.

Standard result

Theorem

Continuity, Monotonicity, Independence, Anonymity jointly imply $\succeq$ *is representable by the continuous function* $I : S_e^n \to \mathbb{R}$ *where* $I(\mathbf{s}; e) = \Phi\left(\sum_{i=1}^n d(s_i, e), e\right)$*, where* $d : S \to \mathbb{R}$ *is a continuous function that is strictly increasing (decreasing) in its first argument if* $s_i > e$ $(s_i < e)$*.*

Corollary

Inequality is total "distance" from equality. Distance d is continuous. $d(s, e)$ *is increasing in status if you move away from the reference point.*

Structure Theorem

- We need more structure on the problem
- **[Scale invariance 1]** For all $\lambda \in \mathbb{R}_+$: if $\mathbf{s}, \mathbf{s}', \lambda\mathbf{s}, \lambda\mathbf{s}' \in S^n$ and $e, e' \in S$ then $(\mathbf{s}, e) \sim (\mathbf{s}', e') \Rightarrow (\lambda\mathbf{s}, e) \sim (\lambda\mathbf{s}', e')$.
- **[Scale invariance 2]** For all $\lambda \in \mathbb{R}_+$: if $\mathbf{s}, \mathbf{s}', \lambda\mathbf{s}, \lambda\mathbf{s}' \in S^n$ and $e, e', \lambda e, \lambda e' \in S$ then $(\mathbf{s}, e) \sim (\mathbf{s}', e') \Rightarrow (\lambda\mathbf{s}, \lambda e) \sim (\lambda\mathbf{s}', \lambda e')$

Theorem

Impose also Scale irrelevance 1. Then $d(s, e) = A(e)\, s^{\alpha(e)}$

Theorem

Impose instead Scale Invariance 2. Then $d(s, e) = e^{\beta} \phi\left(\frac{s}{e}\right)$ *.where* β *is a constant and* ϕ *is arbitrary*

Corollary

Inequality represented as $I_{\alpha}(\mathbf{s}; e) := \frac{1}{\alpha[\alpha-1]}\left[\frac{1}{n}\sum_{i=1}^{n} s_i^{\alpha} - e^{\alpha}\right]$

A usable inequality index?

- A *class* of functions available as inequality measures:
  - $\Phi(I_\alpha(\mathbf{s};e), e)$
  - $e = \eta(\mathbf{s})$, the reference point
  - $I_\alpha(\mathbf{s};e) := \frac{1}{\alpha[\alpha-1]}\left[\frac{1}{n}\sum_{i=1}^{n} s_i^\alpha - e^\alpha\right]$
- Do functions $\Phi(I_\alpha(\mathbf{s};e), e)$ "look like" inequality measures?
  - transfer principle?
  - reference point?
  - sensitivity to parameters
- What is the appropriate form for Φ?
  - may depend on the reference status e
  - may depend on interpretation

Four distributional scenarios (1)

	Case 0		Case 1		Case 2		Case 3	
	n_k	s_i	n_k	s_i	n_k	s_i	n_k	s_i
B	0		25	1	0		25	1
E	50	1	25	3/4	50	1	25	3/4
G	25	1/2	25	1/2	50	1/2	50	1/2
N	25	1/4	25	1/4	0		0	
$\mu(\mathbf{s})$		11/16		5/8		3/4		11/16

- n_k is # persons in category $k \in \{\mathrm{B}, \mathrm{E}, \mathrm{G}, \mathrm{N}\}$
- $s_i = \frac{1}{n} \sum_{\ell=1}^{k(i)} n_\ell$ – *downward*-looking status

Four distributional scenarios

	Case 0		Case 1		Case 2		Case 3	
	n_k	s_i'	n_k	s_i'	n_k	s_i'	n_k	s_i'
B	0		25	$1/4$	0		25	$1/4$
E	50	$1/2$	25	$1/2$	50	$1/2$	25	$1/2$
G	25	$3/4$	25	$3/4$	50	1	50	1
N	25	1	25	1	0		0	
$\mu(\mathbf{s})$		$11/16$		$5/8$		$3/4$		$11/16$

- n_k is # persons in category $k \in \{\mathrm{B}, \mathrm{E}, \mathrm{G}, \mathrm{N}\}$
- $s_i' = \frac{1}{n} \sum_{\ell=k(i)}^{K} n_\ell$ – *upward*-looking status

Four distributional scenarios (2)

	Case 0		Case 1		Case 2		Case 3	
	n_k	s_i	n_k	s_i	n_k	s_i	n_k	s_i
B	0		25	1	0		25	1
E	50	1	25	$3/4$	50	1	25	$3/4$
G	25	$1/2$	25	$1/2$	50	$1/2$	50	$1/2$
N	25	$1/4$	25	$1/4$	0		0	
$\mu(\mathbf{s})$		$11/16$		$5/8$		$3/4$		$11/16$

- Case 0 to Case 1:
  - 25 people promoted from E to B
  - if e equals to any of values taken by $\mu(\mathbf{s})$
  - then inequality increases

Four distributional scenarios (3)

	Case 0		Case 1		Case 2		Case 3	
	n_k	s_i	n_k	s_i	n_k	s_i	n_k	s_i
B	0		25	1	0		25	1
E	50	1	25	3/4	50	1	25	3/4
G	25	1/2	25	1/2	50	1/2	50	1/2
N	25	1/4	25	1/4	0		0	
$\mu(\mathbf{s})$		11/16		5/8		3/4		11/16

- Case 0 to Case 2:
    - 25 people promoted from N to G
    - if e equals to any of values taken by $\mu(\mathbf{s})$
    - then inequality decreases

Transfer Principle again

	Case 0		Case 1		Case 2		Case 3	
	n_k	s_i	n_k	s_i	n_k	s_i	n_k	s_i
B	0		25	1	0		25	1
E	50	1	25	$3/4$	50	1	25	$3/4$
G	25	$1/2$	25	$1/2$	50	$1/2$	50	$1/2$
N	25	$1/4$	25	$1/4$	0		0	
$\mu(\mathbf{s})$		$11/16$		$5/8$		$3/4$		$11/16$

- Case 0 to Case 1: inequality increases
- Case 0 to Case 2: inequality decreases
- Case 0 to Case 3: combination results in ambiguous change

Reference point

- **Mean status:** $e = \eta(\mathbf{s}) = \mu(\mathbf{s})$
  - for continuous distributions will equal 0.5
  - for categorical data, there is no counterpart to fixed-mean assumption in income-inequality analysis
- **Median status**: $e = \eta(\mathbf{s}) = \text{med}(\mathbf{s})$
  - not well-defined: any value in interval $M(\mathbf{s})$
  - $M(\mathbf{s}) = [1/2, 1)$ in cases 0 and 2
  - $M(\mathbf{s}) = [1/2, 3/4)$ in cases 1 and 3
- **Max status**: $e = 1$
  - for constant e this is only value that makes sense
- **Min status**: $e = 0$
  - counterpart for peer-exclusive case

Sensitivity

- α captures the sensitivity of measured inequality
- If α is high $I_\alpha(\mathbf{s}; e) = \frac{1}{\alpha[\alpha-1]}\left[\frac{1}{n}\sum_{i=1}^{n} s_i^\alpha - e^\alpha\right]$, sensitive to high status-inequality
- If $\alpha = 0$ then $I_0(\mathbf{s}; e) = -\frac{1}{n}\sum_{i=1}^{n} \log s_i + \log e$,
- If $e = \mu(\mathbf{s})$ and $\alpha = 1$ then $\frac{1}{n}\sum_{i=1}^{n} s_i \log s_i - e \log e$

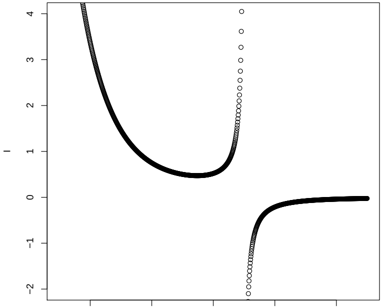
Behaviour of $I_0(\mathbf{s}; e)$

	Case 0	Case 1	Case 2	Case 3
$\mu(\mathbf{s})$	$^{11}/_{16}$	$^{5}/_{8}$	$^{3}/_{4}$	$^{11}/_{16}$
$\text{med}_1(\mathbf{s})$	$^{3}/_{4}$	$^{5}/_{8}$	$^{3}/_{4}$	$^{5}/_{8}$
$\text{med}_2(\mathbf{s})$	$^{1}/_{2}$	$^{1}/_{2}$	$^{1}/_{2}$	$^{1}/_{2}$
$I_0(\mathbf{s};\ \mu(\mathbf{s}))$	0.1451	0.1217	0.0588	0.0438
$I_0(\mathbf{s};\ \text{med}_1(\mathbf{s}))$	0.2321	0.1217	0.0588	-0.0515
$I_0(\mathbf{s};\ \text{med}_2(\mathbf{s}))$	-0.1732	-0.1013	-0.3465	-0.2746
$I_0(\mathbf{s};\ 1)$	0.5198	0.5917	0.3465	0.4184

- $I_0(\mathbf{s};\ \mu(\mathbf{s}))$, $I_0(\mathbf{s};\ \text{med}_1(\mathbf{s}))$: inequality *decreases* for
  - Case 0 to 1, or Case 2 to 3
  - movement changes both the $\mu(\mathbf{s})$ and $\text{med}_1(\mathbf{s})$ ref points
- $I_0(\mathbf{s};\ \text{med}_2(\mathbf{s})) < 0$ for *all* cases in example!
- But $I_0(\mathbf{s}; 1)$ seems sensible

Inequality measure

- For ordinal data, peer-inclusive status
- $I_\alpha(\mathbf{s},1) = \begin{cases} \frac{1}{\alpha(\alpha-1)}\left[\frac{1}{n}\sum_{i=1}^{n} s_i^{\alpha} - 1\right], & \text{if } \alpha \neq 0, \alpha < 1 \\ -\frac{1}{n}\sum_{i=1}^{n} \log s_i. & \text{if } \alpha = 0 \end{cases}$



Implementation

- Description of sample

$$x_i = \begin{cases} 1 & \text{with sample proportion } p_1 \\ 2 & \text{with sample proportion } p_2 \\ \dots & \\ K & \text{with sample proportion } p_K \end{cases},$$

- Point estimate of the index:
  - $$I_\alpha = \begin{cases} \frac{1}{\alpha(\alpha-1)}\left[\sum_{i=1}^{K} p_i \left[\sum_{j=1}^{i} p_j\right]^\alpha - 1\right] & \text{if } \alpha \neq 0{,}1 \\ -\sum_{i=1}^{K} p_i \log\left[\sum_{j=1}^{i} p_j\right] & \text{if } \alpha = 0 \end{cases}$$
  - function of K parameter estimates $(p_1, p_2, \dots, p_K)$ following a multinomial

Asymptotics

- From the CLT I_α is asymptotically Normally distributed
- Estimator of cov matrix of $(p_1, p_2, \ldots, p_k)$ is

$$\Sigma = \frac{1}{n}\begin{bmatrix} p_1(1-p_1) & -p_1p_2 & \ldots & -p_1p_K \\ -p_2p_1 & p_2(1-p_2) & \ldots & -p_2p_K \\ \vdots & \vdots & \vdots & \vdots \\ -p_Kp_1 & -p_Kp_2 & \ldots & p_K(1-p_K) \end{bmatrix}$$

- $\widehat{\mathrm{Var}}(I_\alpha) = D\Sigma D^\top$ with $D = \left[\frac{\partial I_\alpha}{\partial p_1}; \quad \frac{\partial I_\alpha}{\partial p_2}; \ldots; \quad \frac{\partial I_\alpha}{\partial p_K}\right]$
- $\frac{\partial I_\alpha}{\partial p_l} = \frac{1}{\alpha(\alpha-1)}\left(\left[\sum_{i=1}^{l} p_i\right]^\alpha + \alpha \sum_{i=l}^{K-1} p_i \left[\sum_{j=1}^{i} p_j\right]^{\alpha-1}\right), \alpha \neq 0$
- $\frac{\partial I_0}{\partial p_l} = -\log\left[\sum_{j=1}^{l} p_j\right] - \sum_{i=l}^{K-1} p_i \left[\sum_{j=1}^{i} p_j\right]^{-1}$

Confidence Intervals

- 3 variants of CIs: Asymptotic, Percentile Bootstrap, Studentized Bootstrap
- $CI_{asym} = [I_\alpha - c_{0.975}\widehat{\text{Var}}(I_\alpha)^{1/2}\,;\, I_\alpha + c_{0.975}\widehat{\text{Var}}(I_\alpha)^{1/2}]$
  - $c_{0.975}$ from the Student distribution $T(n-1)$
  - do not always perform well in finite samples
- Bootstraps: generate resamples, $b = 1, \ldots, B$
  - for each resample b compute the inequality index
  - obtain B bootstrap statistics, I_α^b
  - also B bootstrap t-statistics $t_\alpha^b = (I_\alpha^b - I_\alpha)/\widehat{\text{Var}}(I_\alpha^b)^{1/2}$
- $CI_{perc} = [c^b_{0.025}\,;\, c^b_{0.975}]$
  - $c^b_{0.025}$ and $c^b_{0.975}$ are from EDF of bootstrap statistics
- $CI_{stud} = [I_\alpha - c^*_{0.975}\widehat{\text{Var}}(I_\alpha)^{1/2}\,;\, I_\alpha - c^*_{0.025}\widehat{\text{Var}}(I_\alpha)^{1/2}]$
  - $c^*_{0.025}$ and $c^*_{0.975}$ are from EDF of the bootstrap t-statistics

Performance Test

- Take an example with 3 ordered categories ($K = 3$)
- Samples are drawn from a multinomial distribution with probabilities $\pi = (0.3, 0.5, 0.2)$
- Is asymptotic or bootstrap distribution a good approximation of the exact distribution of the statistic?
  - if we are using 95% CIs of I_α
  - coverage error rate should be close to nominal rate, 0.05
- Check coverage error rate of CIs as sample size increases
  - $\alpha = -1, 0, 0.5, 0.99$
  - 199 bootstraps
  - 10 000 replications to compute error rates
  - $n = 20, 50, 100, 200, 500, 1000$

Estimation Methods Compared

	α	-1	0	0.5	0.99
Asymptotic B	$n = 20$	0.0606	0.0417	0.0598	0.0491
	$n = 500$	0.0523	0.0492	0.0521	0.0523
	$n = 1000$	0.0485	0.0540	0.0552	0.0549
Percentile B	$n = 20$	0.0384	0.0981	0.0912	0.1023
	$n = 500$	0.0509	0.0513	0.0552	0.0554
	$n = 1000$	0.0482	0.0556	0.0547	0.0551
Studentized B	$n = 20$	0.1275	0.0843	0.1041	0.1377
	$n = 500$	0.0518	0.0478	0.0429	0.0465
	$n = 1000$	0.0473	0.0522	0.0493	0.0503

- Asymptotic CIs perform OK in finite sample
- Percentile bootstrap performs well for $n > 50$
- Studentized bootstrap does not do well for small samples
- Reliable results for $\alpha = 0.99$ (index is undefined for $\alpha = 1$)

World values survey

- Life satisfaction question:

All things considered, how satisfied are you with your life as a whole these days? Using this card on which 1 means you are "completely dissatisfied" and 10 means you are "completely satisfied" where would you put your satisfaction with your life as a whole? (code one number):

Completely dissatisfied – 1 2 3 4 5 6 7 8 9 10 – Completely satisfied

- Health question:

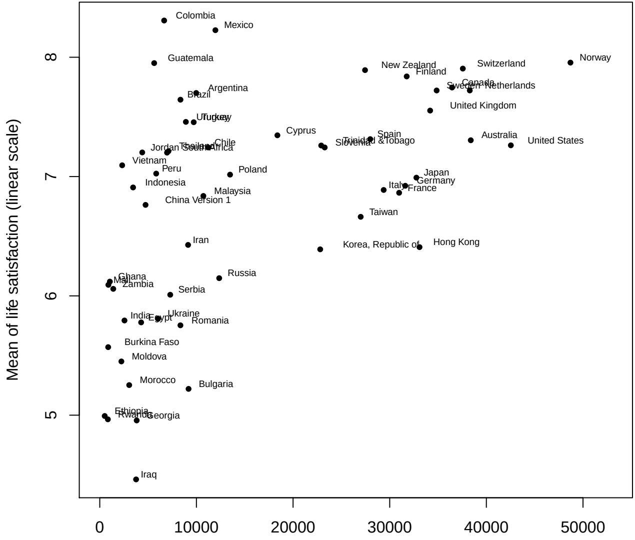
All in all, how would you describe your state of health these days? Would you say it is (read out):

1 Very good, 2 Good, 3 Fair, 4 Poor.

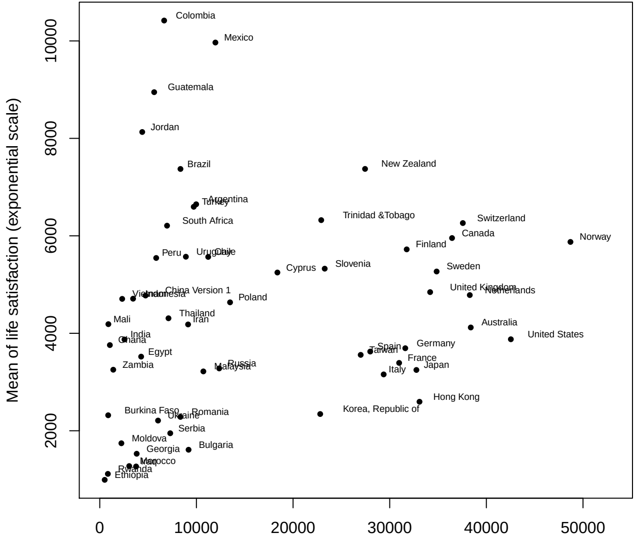
GDP and Life satisfaction

- Cross-country comparison of life satisfaction and GDP/head
  - happiness-income paradox (Easterlin 1974, Clark and Senik 2011)
  - weak relation happiness-income internationally? (Easterlin 1995, Easterlin et al. 2010)
  - or a strong relationship? (Hagerty and Veenhoven 2003, Deaton 2008, Stevenson and Wolfers 2008a, Inglehart et al. 2008)
- How should we quantify life satisfaction?
  - simple linearity of Likert scale? or exponential scale?
  - Ng (1997), Ferrer-i-Carbonell and Frijters (2004), Kristoffersen (2011)
- Is inequality of life satisfaction related to GDP/head?
  - Use I_0 and other members of the same family

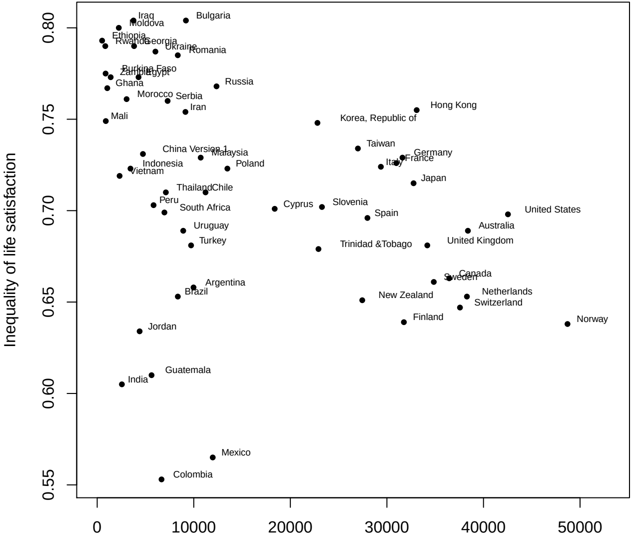
GDP and Life satisfaction (Linear)



GDP and Life satisfaction (Exponential)



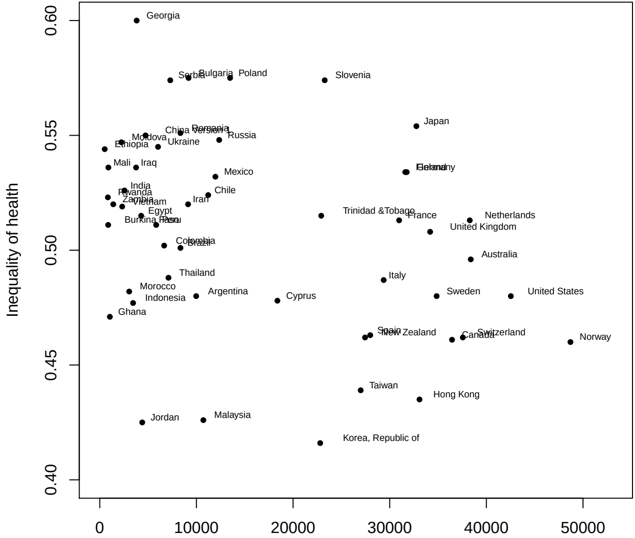
GDP and Inequality of Life satisfaction



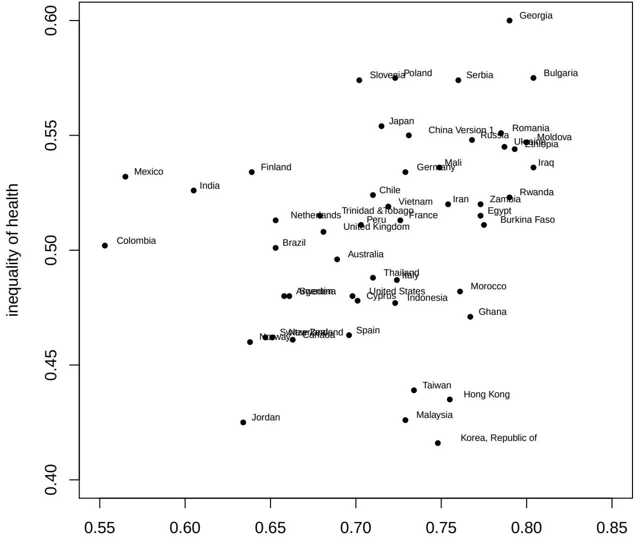
Health status

- Health is HRS
- Cross-country comparison of health and GDP
  - a significant positive relationship? (Deaton 2008)
- Cross-country comparison of inequality of health and Inequality of life satisfaction
  - use same inequality index as for life satisfaction

Inequality of health and GDP



Inequality of health



Application: overview

- Satisfaction / GDP results sensitive to the cardinal interpretation of the answers
  - linear: positive relation below $15 000, flat after that (Layard 2003)
  - exponential: no relation
- OLS estimate of I_0(life satisfaction) on the GDP per capita small and negative
  - happiness-income relationship is weak in cross-country comparisons
- No clear relationship between I_0(health) on GDP per capita
- OLS estimate of I_0(health) on I_0(life satisfaction) produces a slope coefficient not significantly different from zero
  - health-life satisfaction relationship is not significant

Summary

- Inequality with ordinal data is a widespread phenomenon
- Conventional I-measures may make no sense
- Cowell and Flachaire (2014) approach:
  - separates out the issue of status from that of inequality-aggregation
  - allows you to choose “reference status”
  - gives a family of measures
- Nice properties empirically

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