Formal demography as tool to innovate measures & concepts of lifespan and aging

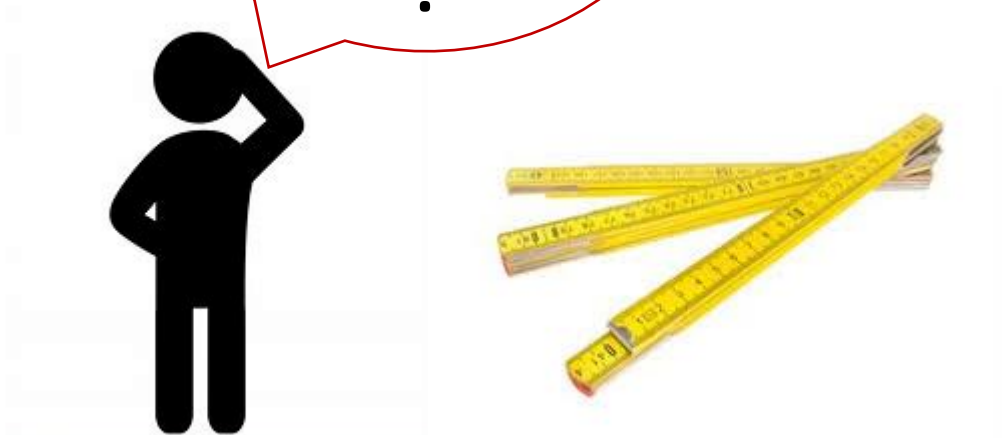
June 9th, 2022

Annette Baudisch

Compare Life Span & Aging across Populations

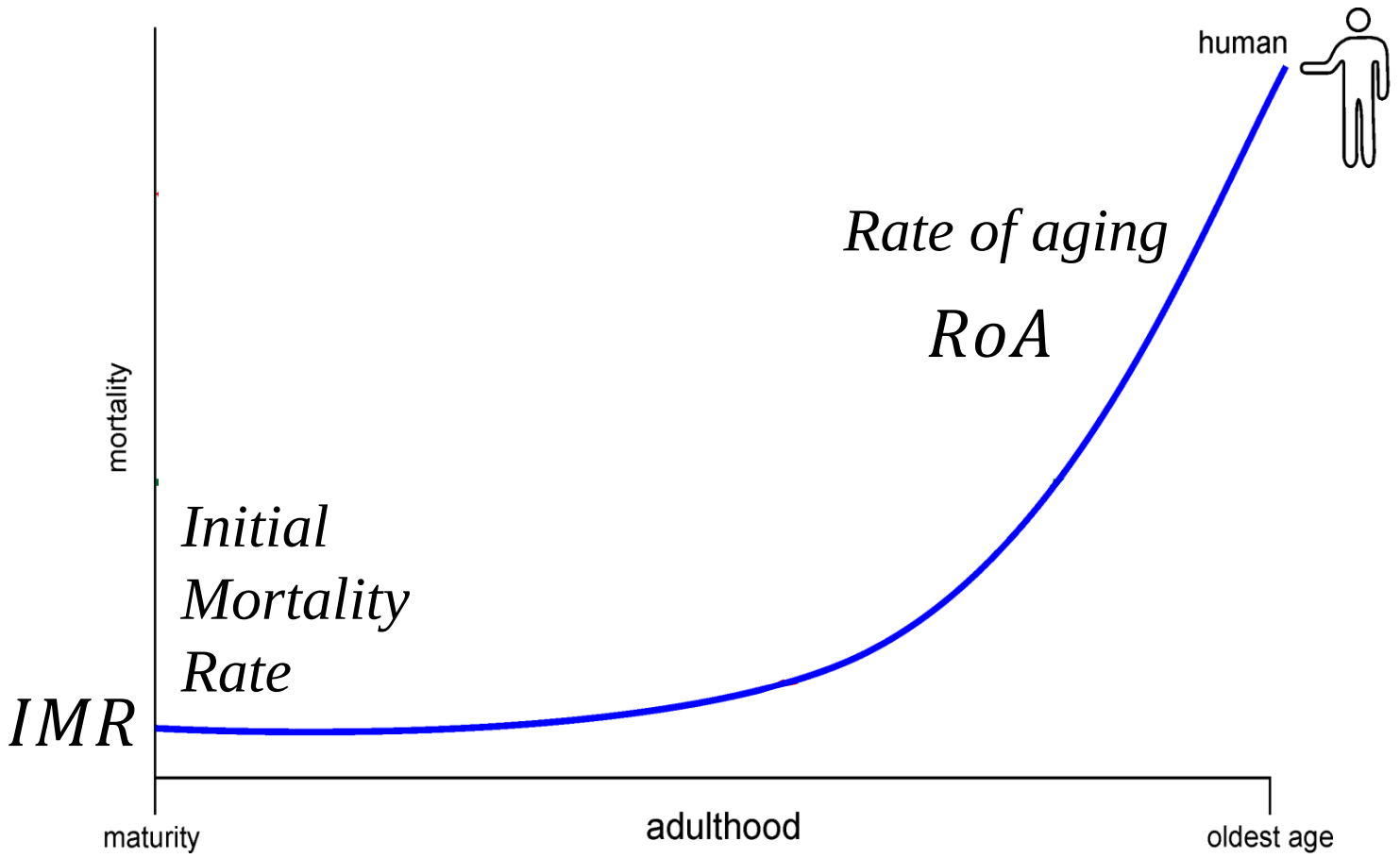
Do the measures I use capture all the signals that are relevant?

?



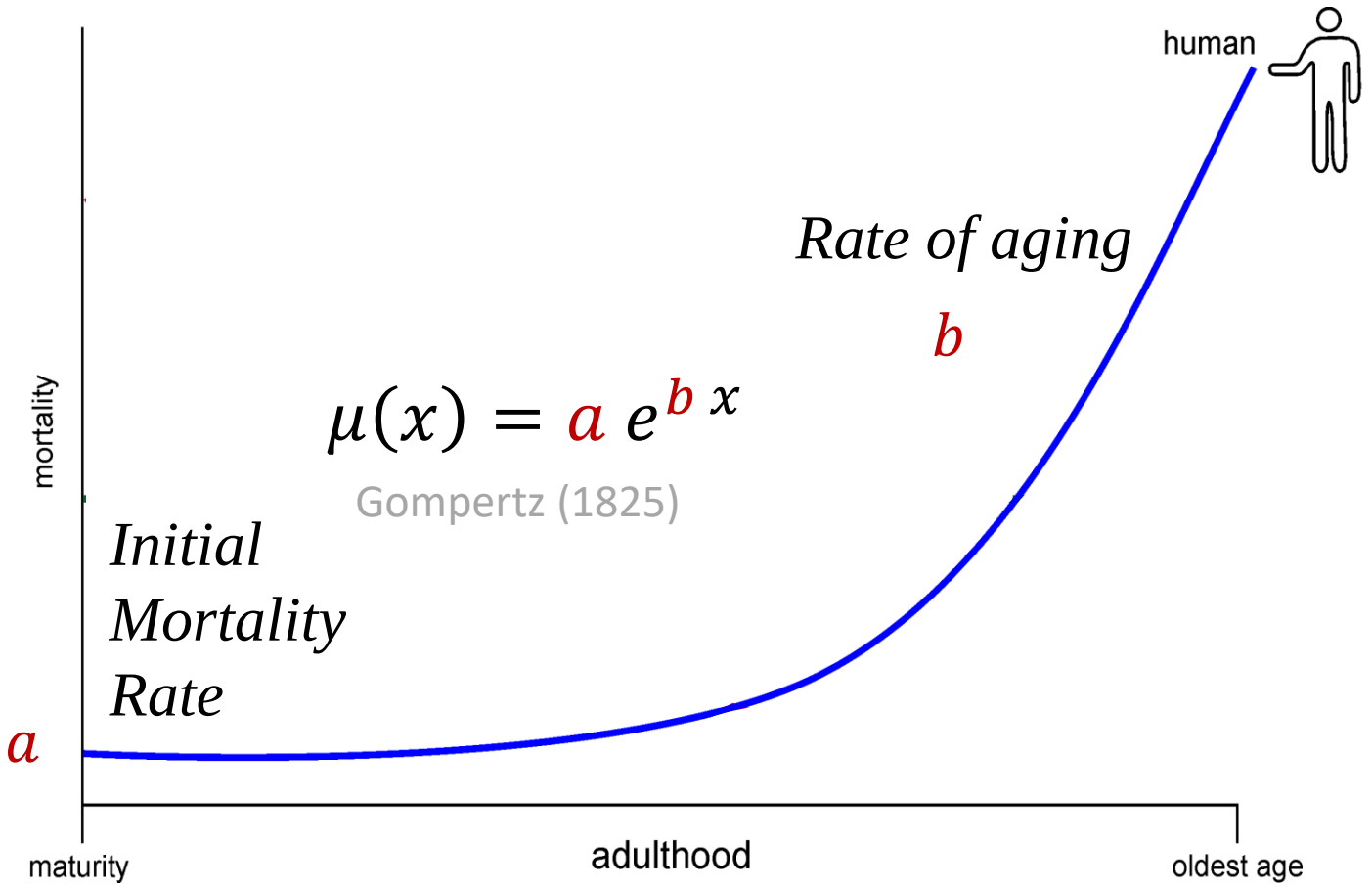
Formal demography as strong & useful tool

Traditional Measures



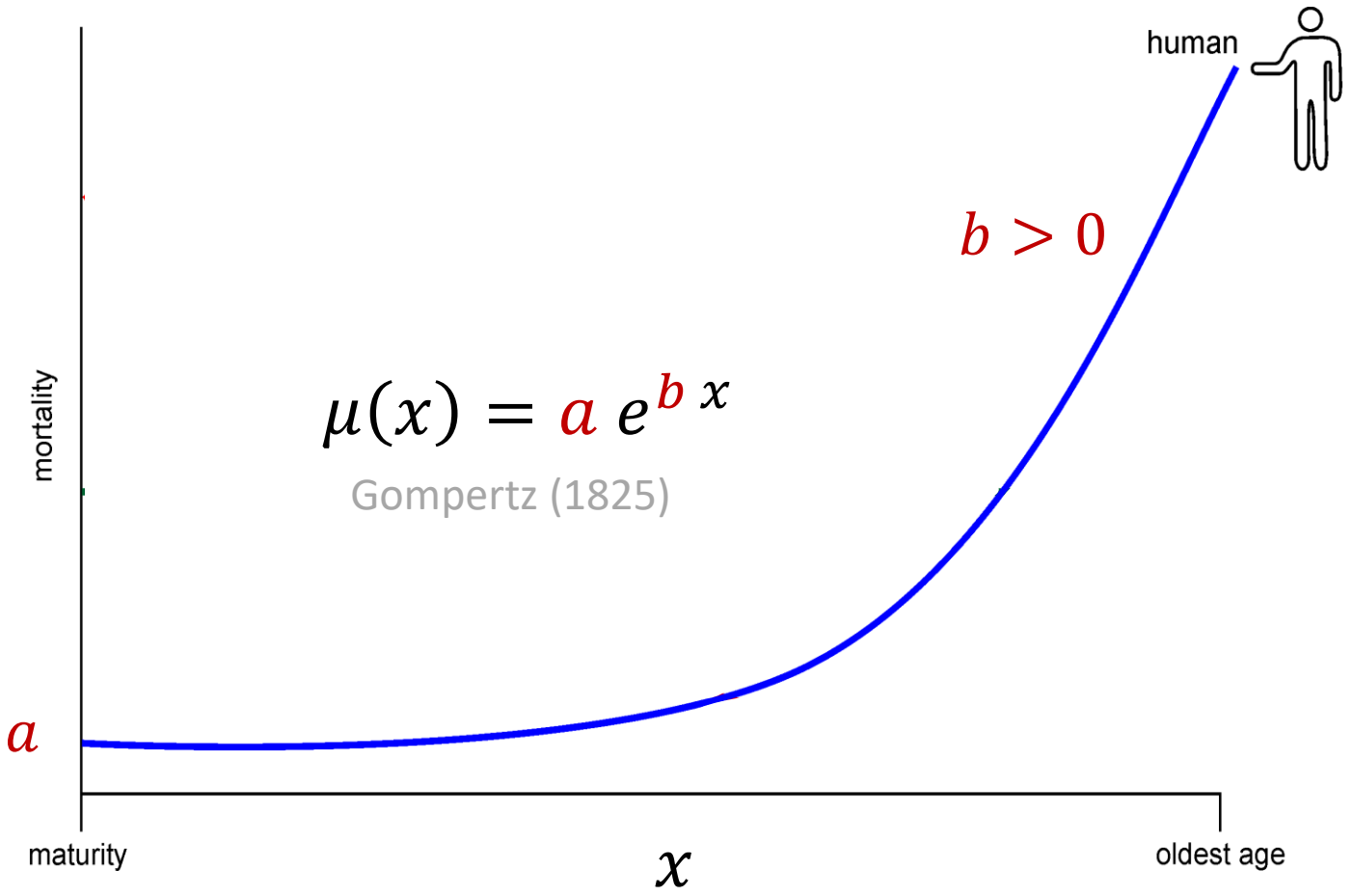
Measures to describe & classify aging patterns

Traditional Measures



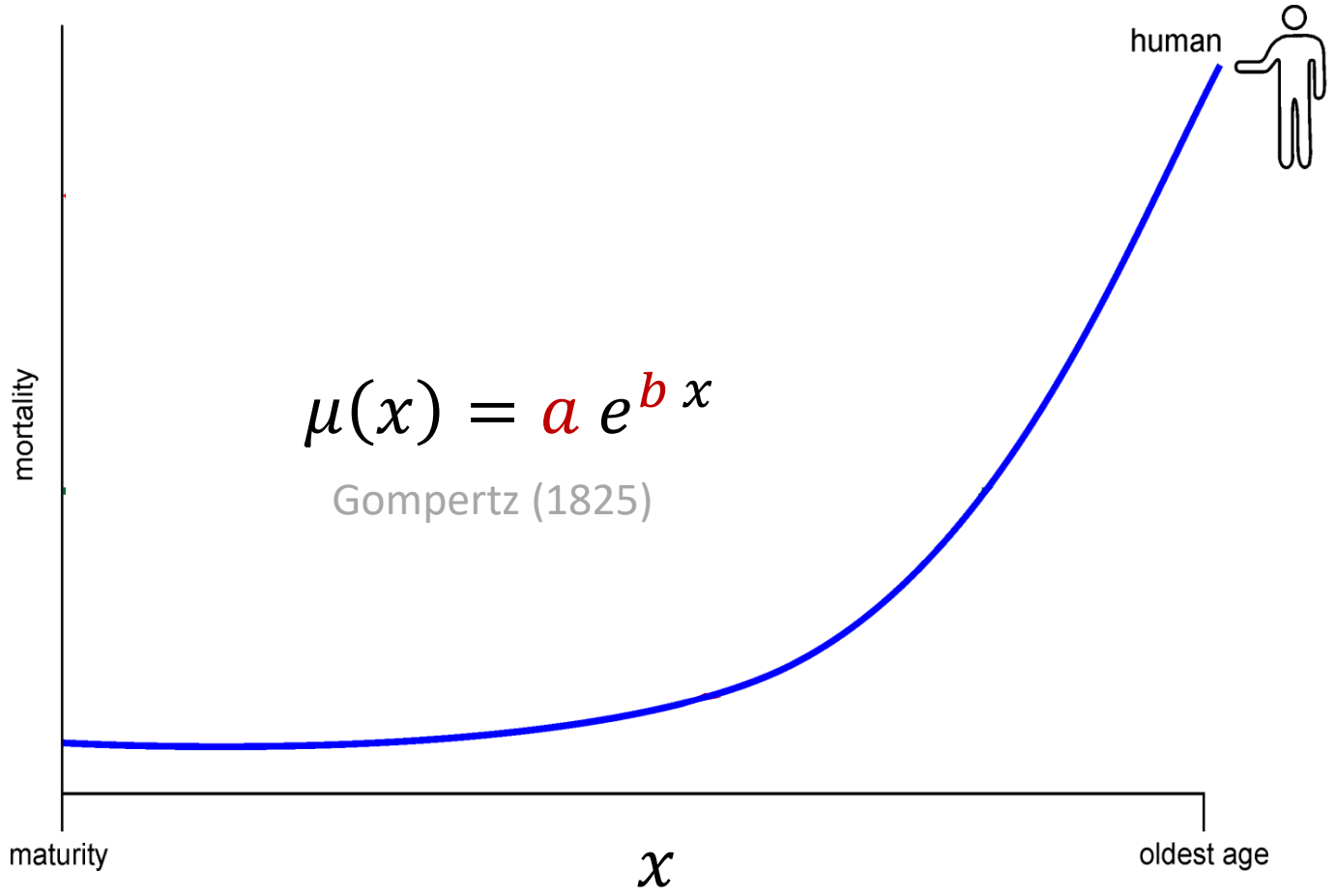
Measures to describe & classify aging patterns

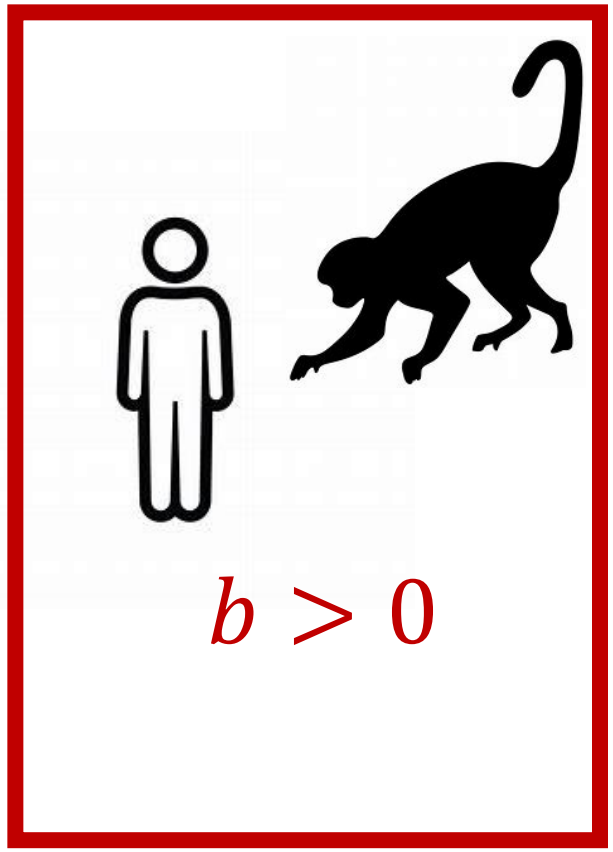
Traditional Measures



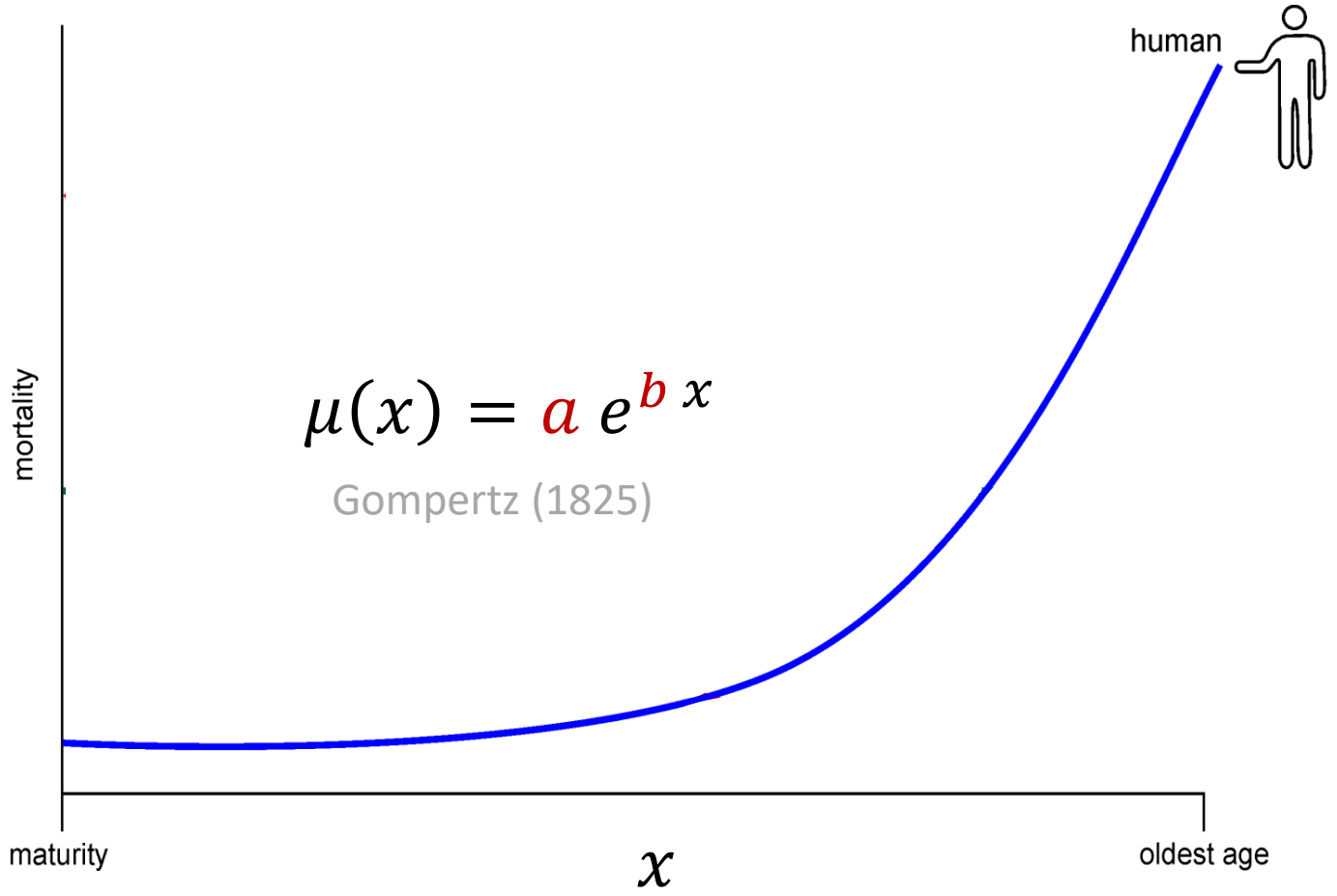
Mathematical function to describe mortality

Traditional Measures





Traditional Measures



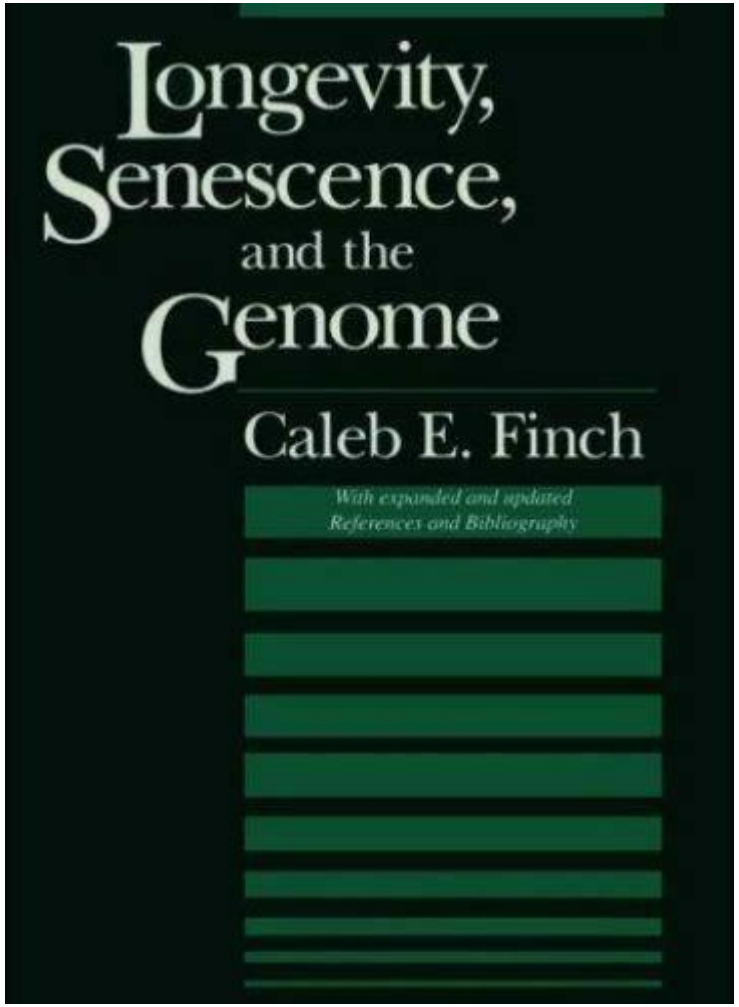
Finch et al. 1990.
Science
(humans, mammals, birds)

Bronikowski et al. 2002.
PNAS
(humans, baboons)

Bronikowski et al. 2011.
Science
(humans, primates)

Empirical diversity of aging patterns

Finch 1990

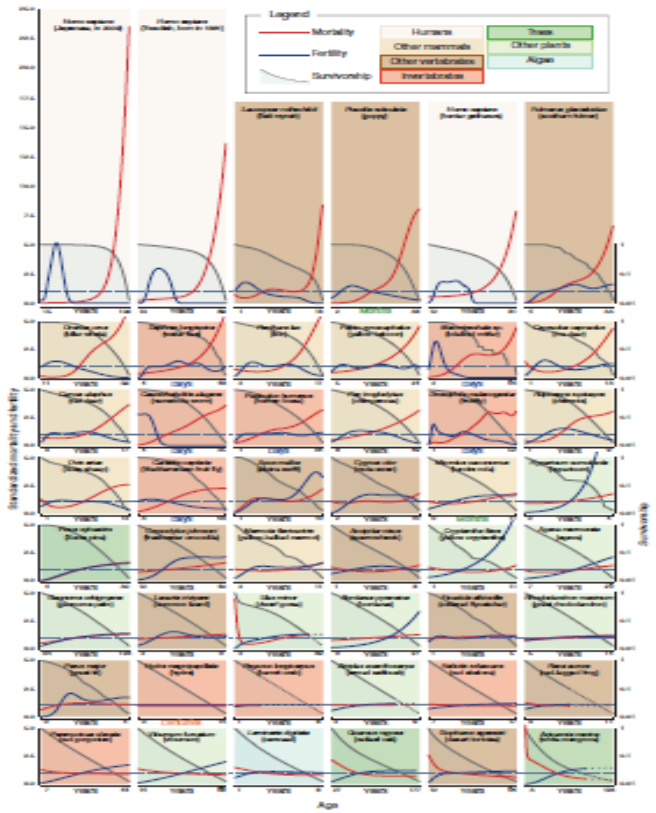


Jones et al 2014 Nature

doi:10.1038/nature12789

Diversity of ageing across the tree of life

Owen R. Jones[1,2*], Alexander Scheuerlein[3*], Roberto Salguero-Gómez[3,4], Carlo Giovanni Camarda[5], Ralf Schaible[3], Brenda B. Casper[6], Johan P. Dahlgren[1,2], Johan Ehrlén[7], María B. García[8], Eric S. Menges[9], Pedro F. Quintana-Ascencio[10], Hal Caswell[2,3,11,12], Annette Baudisch[3] & James W. Vaupel[1,3,13]



Traditional measures capture this diversity

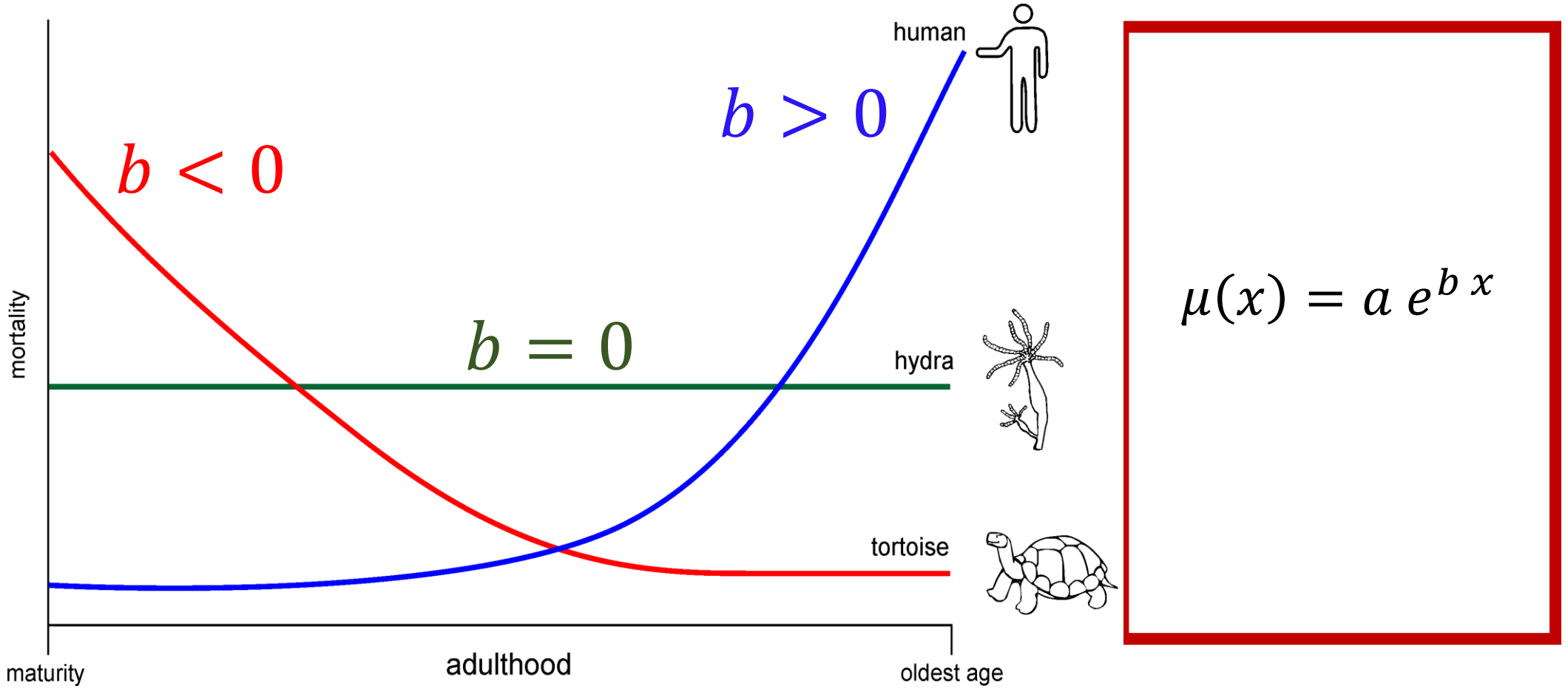


Fig. adapted from Baudisch & Vaupel 2012 Science

But...

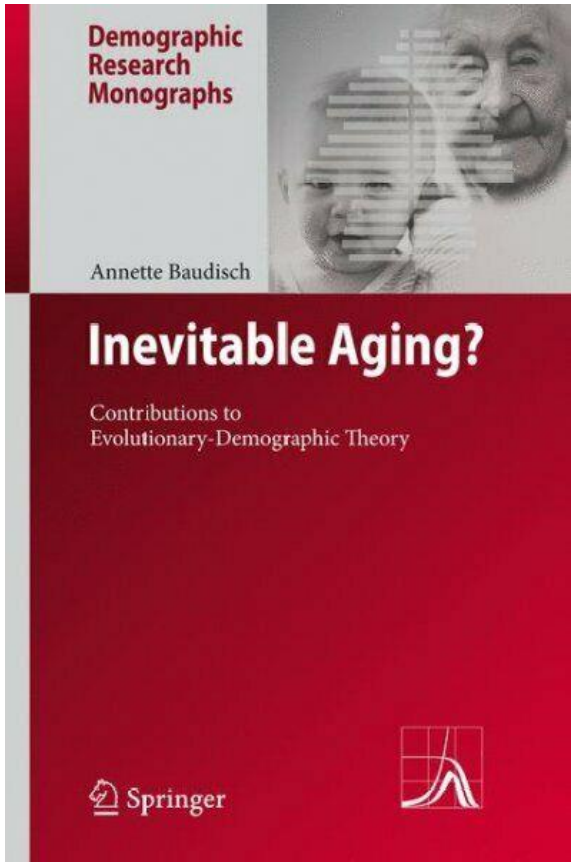
Is it enough to measure the initial mortality rate and the rate of aging to classify aging patterns?

Traditional measures

- well justified (intuitive, widely applicable, flexible, simple)
- but do they capture all relevant dimensions?

Evolutionary demographic theory …

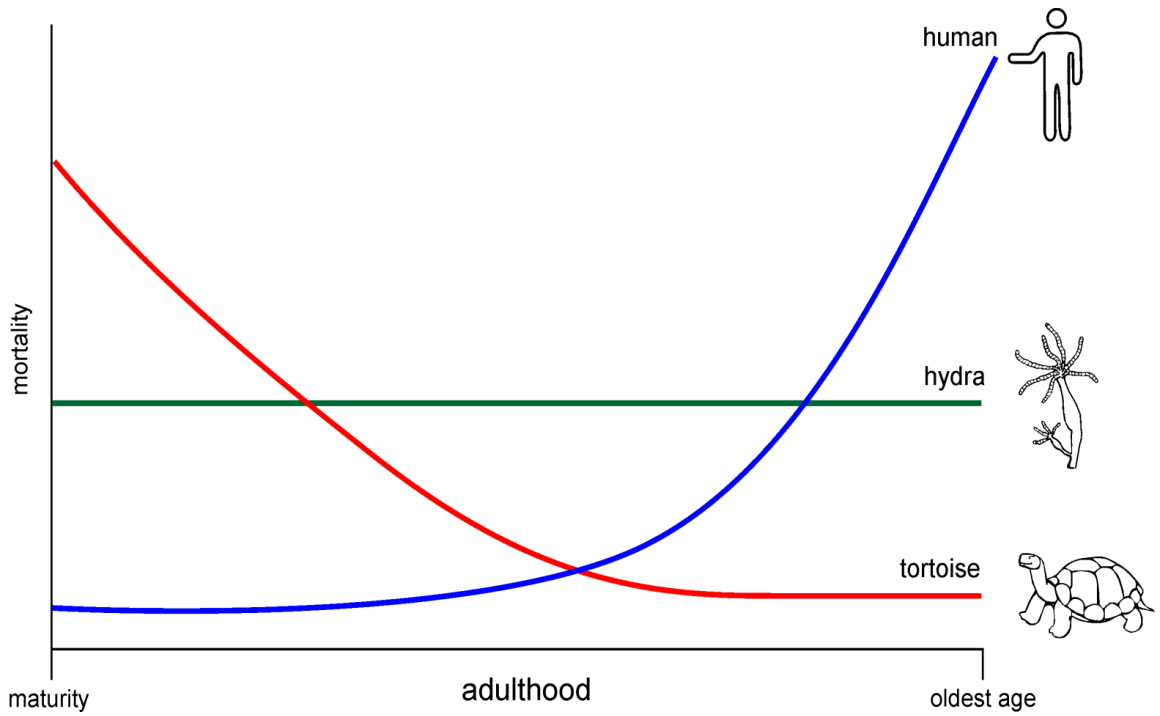
Theoretical diversity of patterns



Open Access Online Available
Baudisch 2008 Springer

Evolutionary demographic models

Vaupel et al 2004
Baudisch 2008
Baudisch & Vaupel 2010



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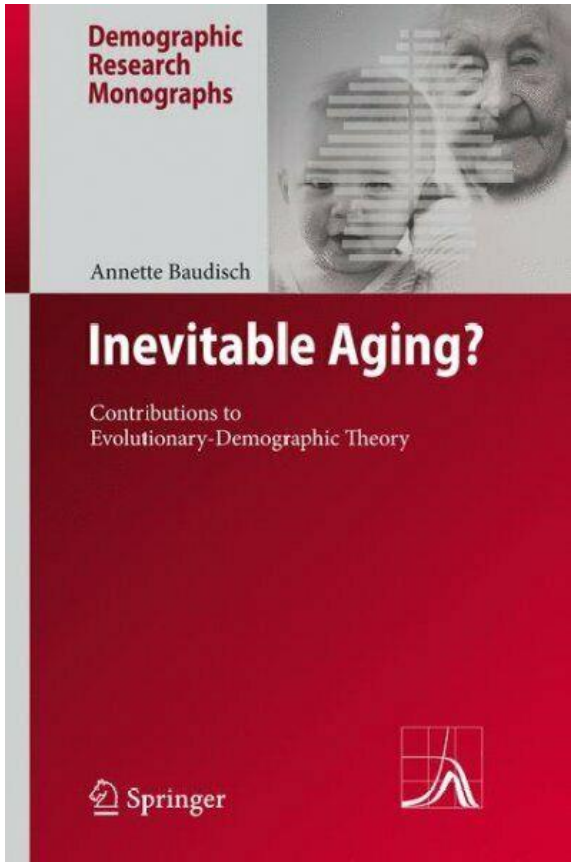
Theoretical diversity of patterns



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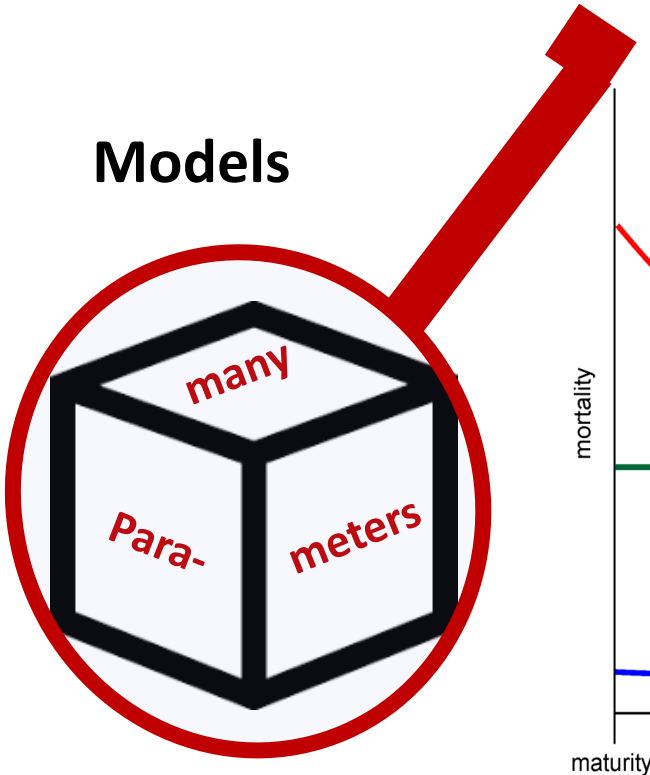

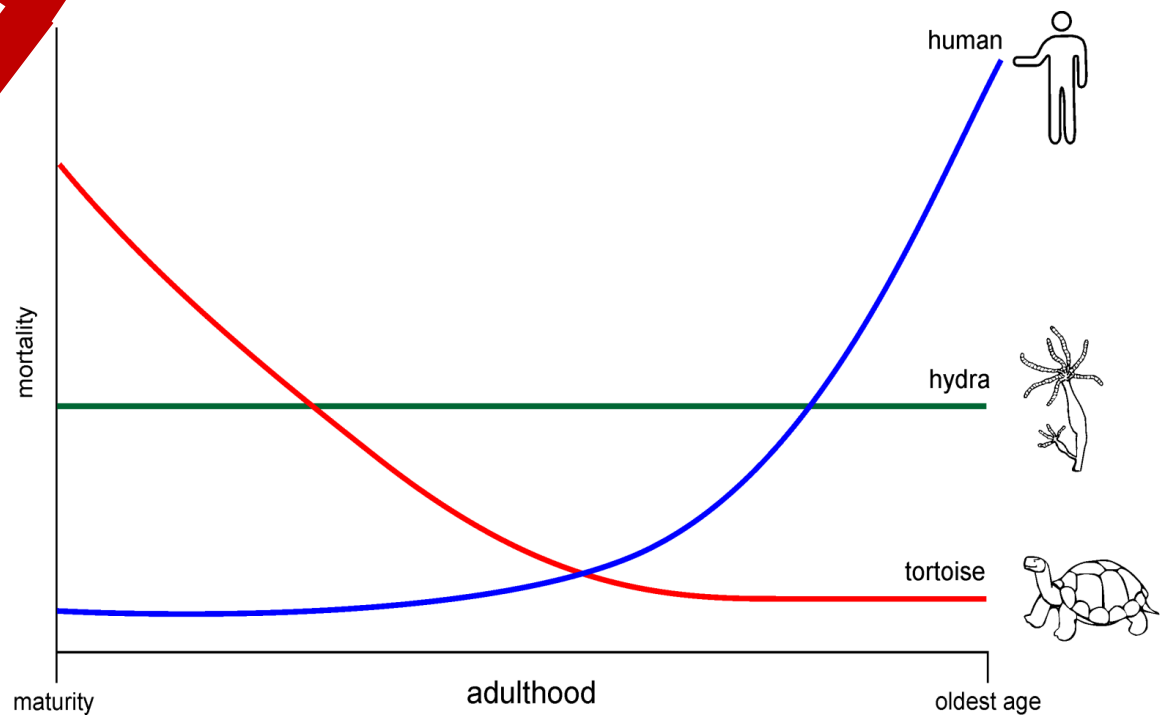

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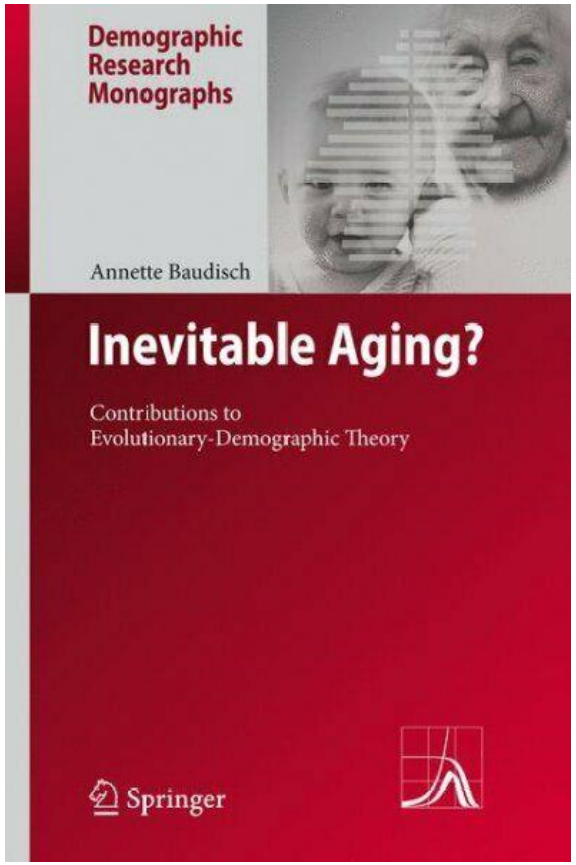

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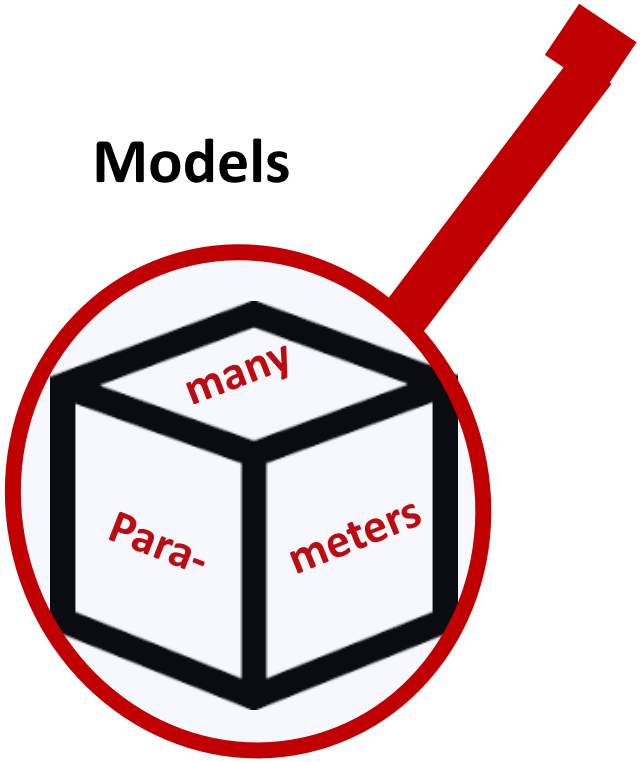
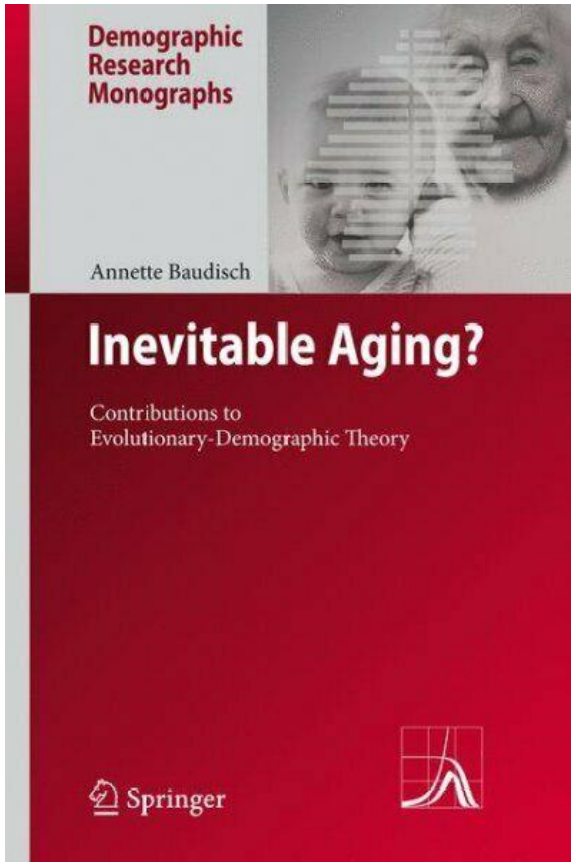


→ Which parameters are important?

→ What do they tell us?

Theoretical diversity of patterns



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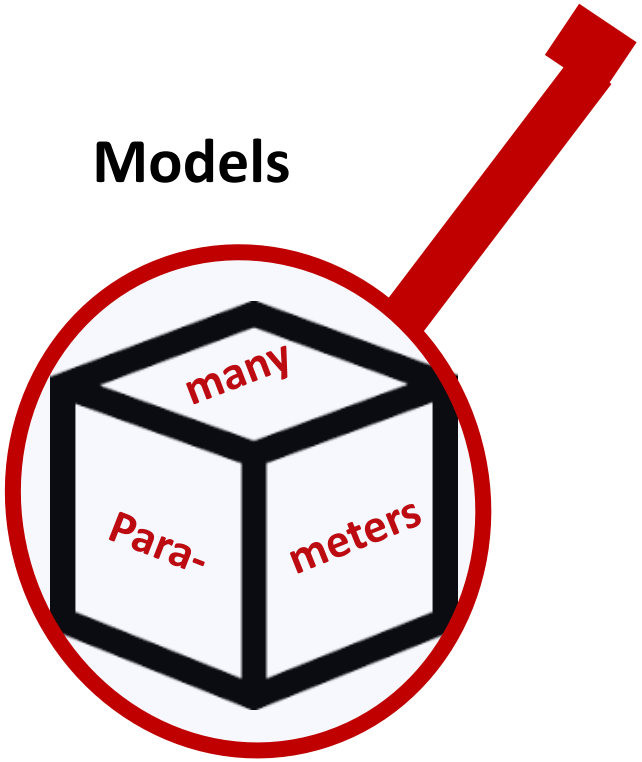
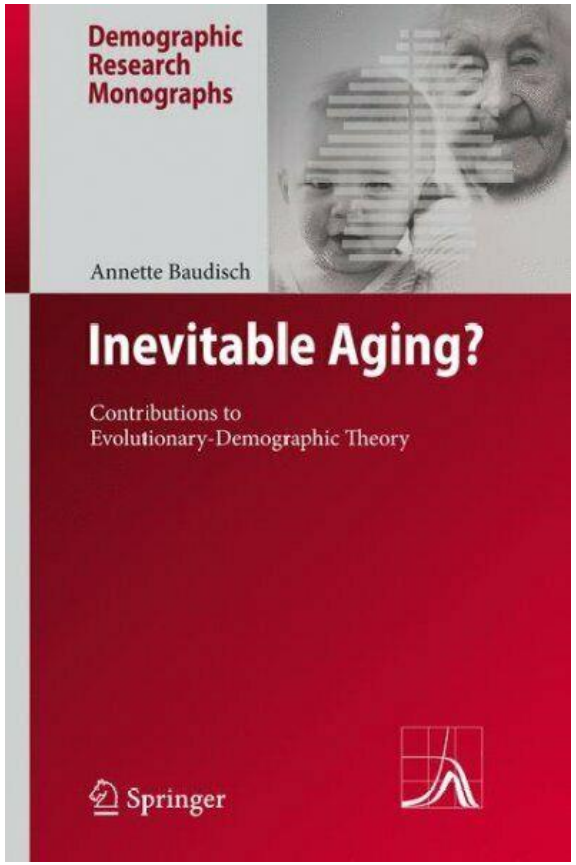


→ Parameters that determine what type of aging pattern evolves are **dimensionless**!

Theoretical diversity of patterns



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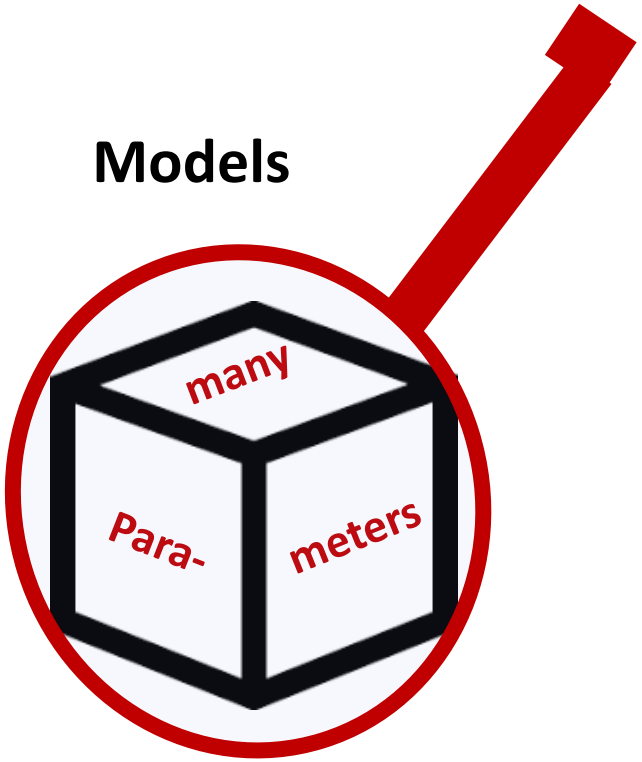


To distinguish different types of aging one needs to **factor out time.**

To reveal a new and relevant signal of what determines aging patterns

→ Distinguish two separate dimensions

Baudisch (2011) The Pace and Shape of Aging. *Methods in Ecology & Evolution*

Two Dimensions of Aging

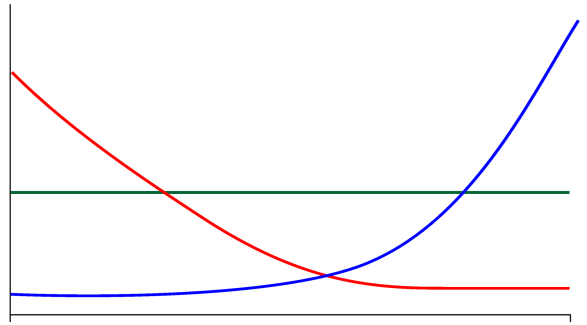
Pace of mortality

Time scale of life

To live how many more or less days, weeks, months, years, or centuries?

Shape of mortality

Time-standardized pattern of mortality over age



To experience mild or strong change in mortality over the life-course, and in what direction?

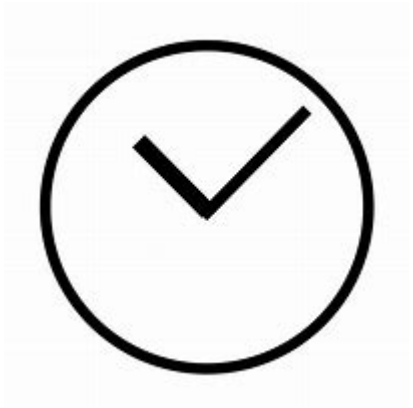
A framework motivated by Theory

Pace of mortality

Time scale of life

-Lifespan

-Death rate



Preferable Measure

Life-expectancy, e0, at initial age 0

Fraction dying at age x

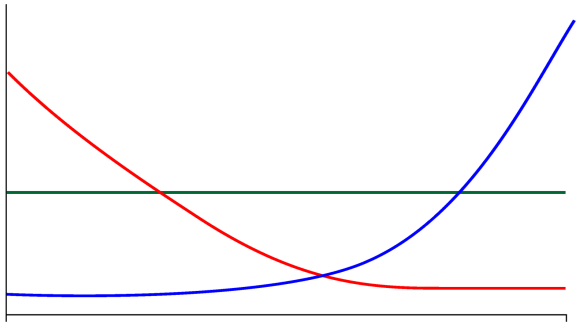
$$e_0 = \int_0^{\omega} x\, f(x)\, dx$$

Wrycza & Baudisch (2014)The Pace of Aging. *Demographic Research*

A framework motivated by Theory

Shape of mortality

Time-standardized pattern over the life course



Preferable Measures

Measures of relative inequality in ages at death

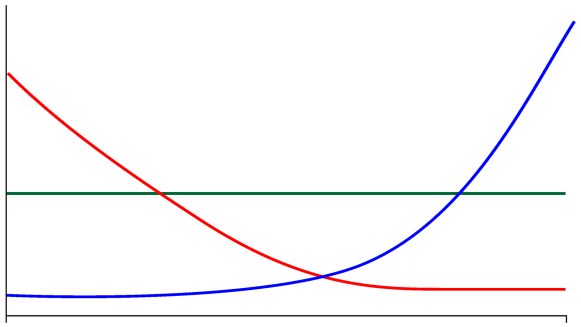
- Gini coefficient
- Life table entropy
- Coeff. of Variation

Wrycza, Missov & Baudisch (2016)
Quantifying the shape of aging.
Demographic Research

A framework motivated by Theory

Shape of mortality

Time-standardized pattern over the life course



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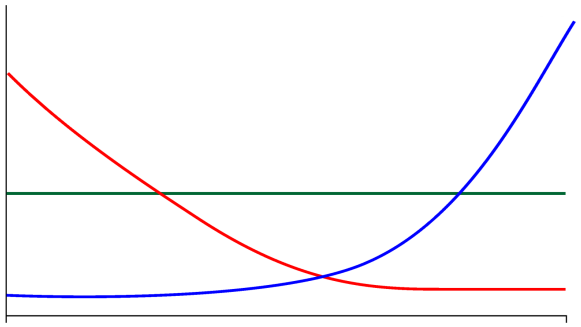


Helpful concept

Life-years lost due to death $e^{\dagger}$

$$e^{\dagger} = \int_0^{\omega} e(x)\, f(x)\, dx$$

Life-years left at age x

Fraction dying at age x

Vaupel and Canudas-Romo, 2003
Goldman and Lord 1986, Hakkert 1987, Vaupel 1986

A framework motivated by Theory

Shape of mortality

Life-years lost / *Life-expectancy*

$$\frac{e^{\dagger}}{e_0}$$

	1950	2010
	$\frac{15.2}{66.1} = 0.23$	$\frac{10.4}{78.9} = 0.13$

Average values across countries in the HMD

Helpful concept

Life-years lost due to death $e^{\dagger}$

$$e^{\dagger} = \int_0^{\omega} e(x)\, f(x)\, dx$$

Life-years left at age x

Fraction dying at age x

Vaupel and Canudas-Romo, 2003
Goldman and Lord 1986, Hakkert 1987, Vaupel 1986

A framework motivated by Theory

Shape of mortality

A measure of
relative lifespan inequality

$$\mathcal{H} = \frac{e^{\dagger}}{e_0}$$

Lifetable Entropy

Leser 1955, Demetrius 1974, Keyfitz 1977

Helpful concept

Life-years lost due to death $e^{\dagger}$

$$e^{\dagger} = \int_0^{\omega} e(x)\, f(x)\, dx$$

Life-years left at age x

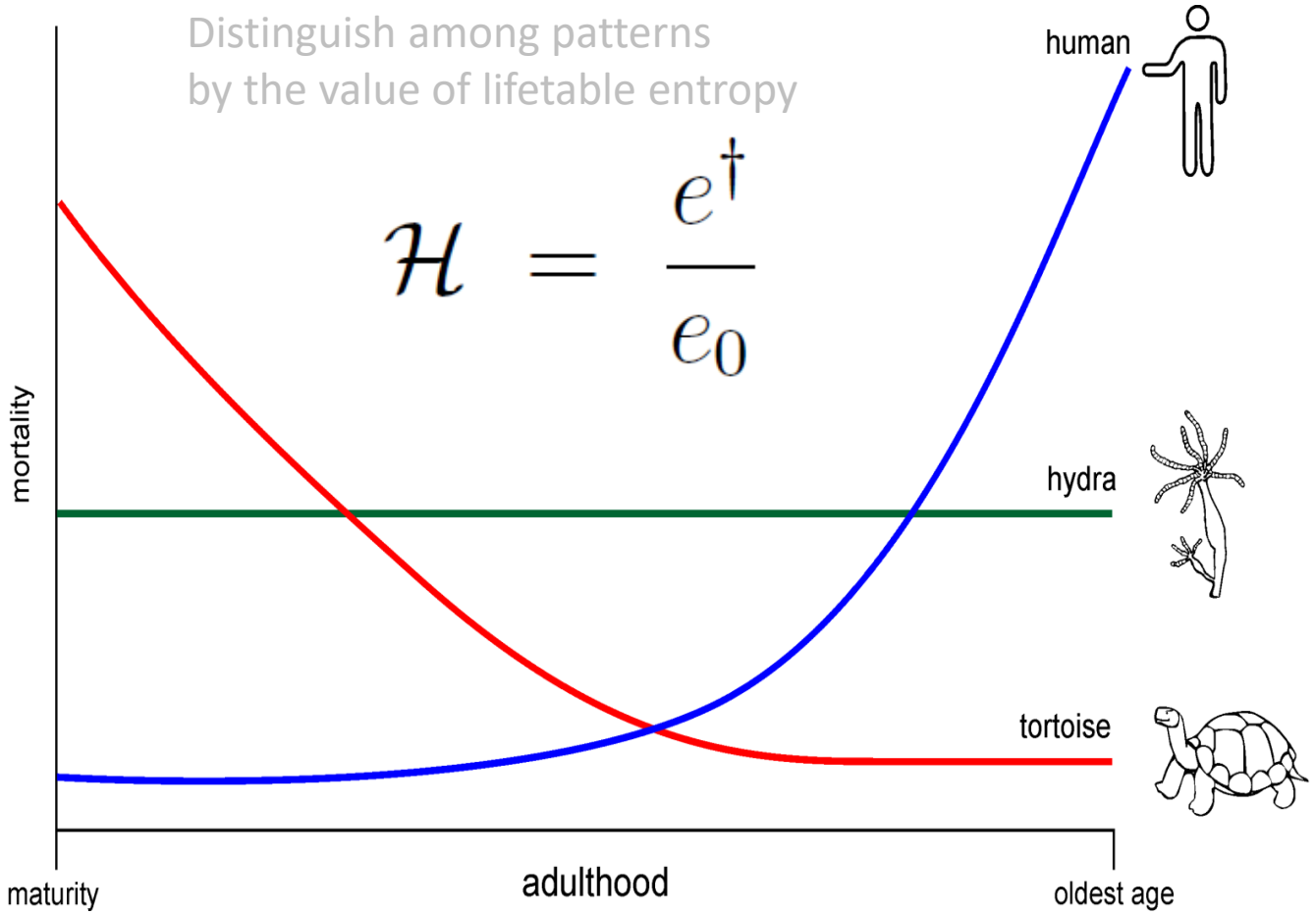
Fraction dying at age x

Vaupel and Canudas-Romo, 2003
Goldman and Lord 1986, Hakkert 1987, Vaupel 1986

Lifespan disparity measures capture **shape of aging**

Distinguish among patterns
by the value of lifetable entropy

$$\mathcal{H} = \frac{e^\dagger}{e_0}$$



$$\mathcal{H} < 1 \quad if \quad e^\dagger < e_0$$

$$\mathcal{H} = 1 \quad if \quad e^\dagger = e_0$$

$$\mathcal{H} > 1 \quad if \quad e^\dagger > e_0$$

An elegant relationship

Lifespan

Lifespan Disparity

$$a\, e_0 + b\, e^{\dagger} = 1$$

Level of Mortality

Rate of Aging

Life expectancy at birth

$$e_0 = \int_0^{\omega} \ell(x)\, dx$$

Preston, Heuveline, Guillot 2000

Life years lost at death

$$e^{\dagger} = -\int_0^{\omega} \ell(x) \ln \ell(x)\, dx$$

Vaupel and Canudas-Romo, 2003

Goldman and Lord 1986, Hakkert 1987, Vaupel 1986

Gompertz Mortality

$$\mu(x) = ae^{bx}$$

Gompertz (1825)

An elegant relationship

Why does it matter?

$$a\,e_0 + b\,e^\dagger = 1$$

How can it be helpful?

Life expectancy at birth

$$e_0 = \int_0^\omega \ell(x)\,dx$$

Preston, Heuveline, Guillot 2000

Life years lost at death

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Goldman and Lord 1986, Hakkert 1987, Vaupel 1986

Gompertz Mortality

$$\mu(x) = ae^{bx}$$

Gompertz (1825)

An elegant relationship

It relates two key demographic summary measures

$$a\, e_0 + b\, e^\dagger = 1$$

for a general mortality model, which broadly captures not just human, but also non-human mortality patterns across adult ages (Finch et al 1990).

Life expectancy at birth

$$e_0 = \int_0^\omega \ell(x)\, dx$$

Preston, Heuveline, Guillot 2000

Life years lost at death

$$e^\dagger = -\int_0^\omega \ell(x) \ln \ell(x)\, dx$$

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Gompertz Mortality

$$\mu(x) = ae^{bx}$$

Gompertz (1825)

An elegant relationship

It aids formal demographic analysis

$$a\, e_0 + b\, e^\dagger = 1$$

and supports increasing interest in the relationship of lifespan and lifespan inequality in particular.

For example:

Life expectancy at birth

$$e_0 = \int_0^\omega \ell(x)\, dx$$

Preston, Heuveline, Guillot 2000

Life years lost at death

$$e^\dagger = -\int_0^\omega \ell(x) \ln \ell(x)\, dx$$

Vaupel and Canudas-Romo, 2003
Goldman and Lord 1986, Hakkert 1987, Vaupel 1986

Gompertz Mortality

$$\mu(x) = ae^{bx}$$

Gompertz (1825)

Dynamics of life expectancy and life span equality

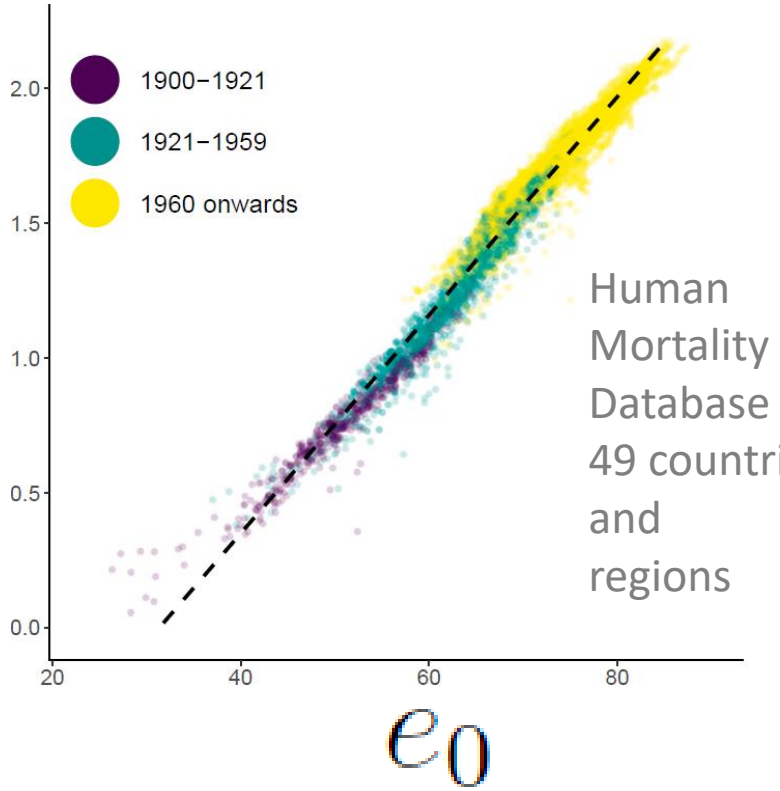
Fig 1 Aburto et al. 2019

Fig 1 Aburto et al. 2019

Relative measure of equality

$$\log \frac{e_0}{e^\dagger}$$

Shape



Human Mortality Database 49 countries and regions

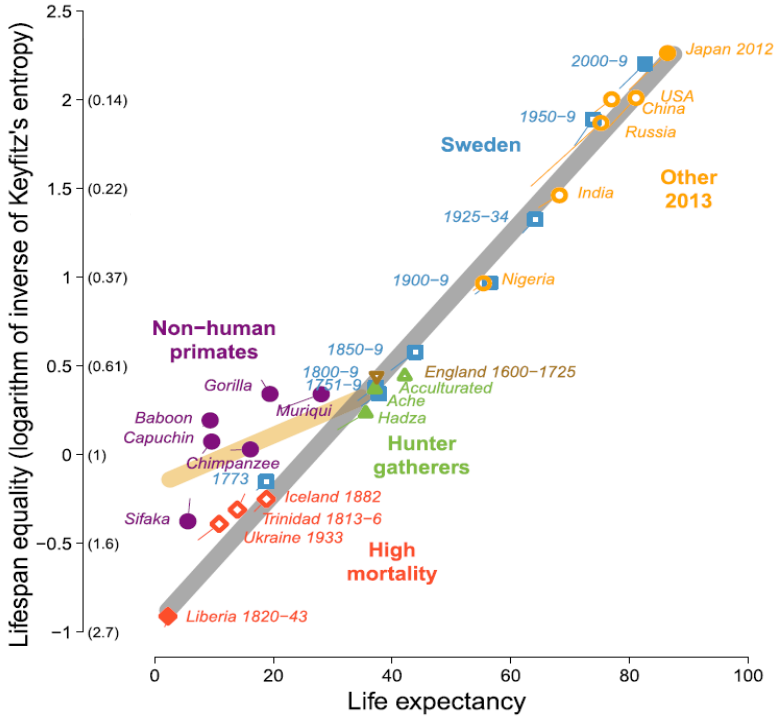
Pace

Aburto et al. *"develop a unifying framework to study life expectancy and life span equality over time, relying on concepts about the pace and shape of aging"*

Lifespan (Pace) vs Lifespan Variation (Shape)

People (and other primates)

$$\log \frac{e_0}{e^\dagger}$$

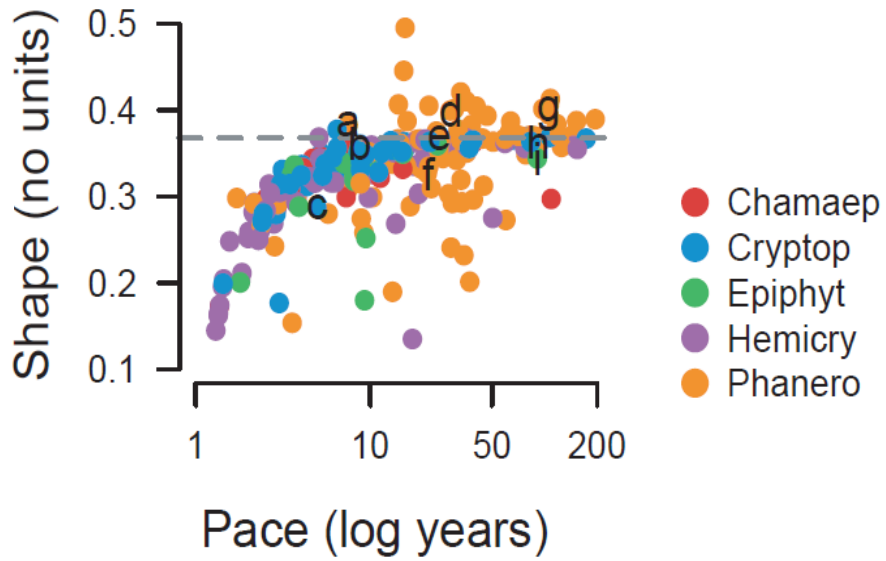


$$e_0$$

Colchero et al 2016, PNAS

Plants (with flowers)

$$\sim \log \frac{e_0}{e^\dagger}$$



$$e_0$$

Baudisch et al 2013, JEcol

An elegant relationship

Support comparative research across the tree of life on lifespan (pace) and lifespan variation (shape)

$$a\, e_0 + b\, e^\dagger = 1$$

Supports to explore dynamics in pace shape space

Life expectancy at birth

$$e_0 = \int_0^\omega \ell(x)\, dx$$

Preston, Heuveline, Guillot 2000

Life years lost at death

$$e^\dagger = -\int_0^\omega \ell(x) \ln \ell(x)\, dx$$

Vaupel and Canudas-Romo, 2003
Goldman and Lord 1986, Hakkert 1987, Vaupel 1986

Gompertz Mortality

$$\mu(x) = ae^{bx}$$

Gompertz (1825)

Further relationships

$$a\acute{e}_{0a} + b\acute{e}_{0b} = 1$$

$$a\acute{e}^{\dagger}{}_{a} + b\acute{e}^{\dagger}{}_{b} = 1$$

$$a\acute{\mathcal{H}}_{a} + b\acute{\mathcal{H}}_{b} = 0$$

Supports exploring dynamics in pace shape space

Notation Relative Change:

$$\acute{x}_{a} = \frac{\frac{dx}{da}}{x}$$

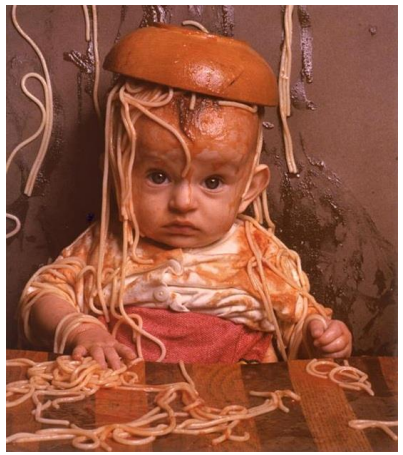
Contributes to a large body of research

e.g.,
Wilmoth, Horiuchi 1999, Edwards, Tuljapurkar 2005,Smits, Monden 2009, Tuljapurkar 2010, Edwards 2011, Baudisch 2011, van Raalte, Caswell 2013, Fernandez, Beltrán-Sánchez 2015, Vaupel et al. 2015, Colchero et al. 2016, van Raalte et al. 2018, Ebeling et al. 2018, Permanyer, Scholl 2019, Aburto et al. 2019, Vaupel et al. 2021

Increasing interest in lifespan inequality and its relationship with lifespan

Extended the framework to fertility

(2019) A pace and shape perspective on fertility
Baudisch & Stott. *Methods in Ecology and Evolution*

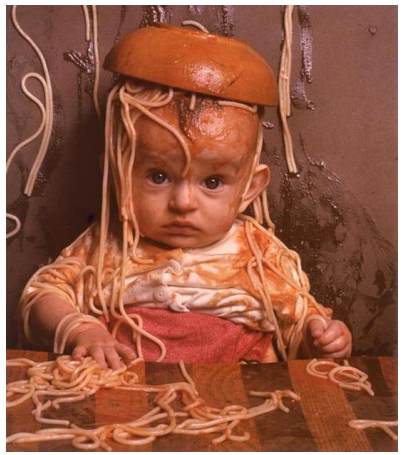


Born once. **Die once.**

(2021) Born once, die once: Life table relationships for fertility
Baudisch & Alvarez. *Demographic Research*

ERC Consolidator grant 2022.

Towards a Transdisciplinary Theory of Birth and Death



Born once. **Die once.**

Using the tools of formal demography to conceptualize and model birth and death of ”individuals”, eventually across disciplines.

Summary & Conclusion

Population aging, species exctinction, sustainability crisis, pandemics,… all major problems of the world result from an imbalance of birth and death processes.

Formal Demography is the key to conceptualize and model birth and death processes (+ migration!) in whatever disciplines.

The world needs more formal demographers!

Comments  Questions

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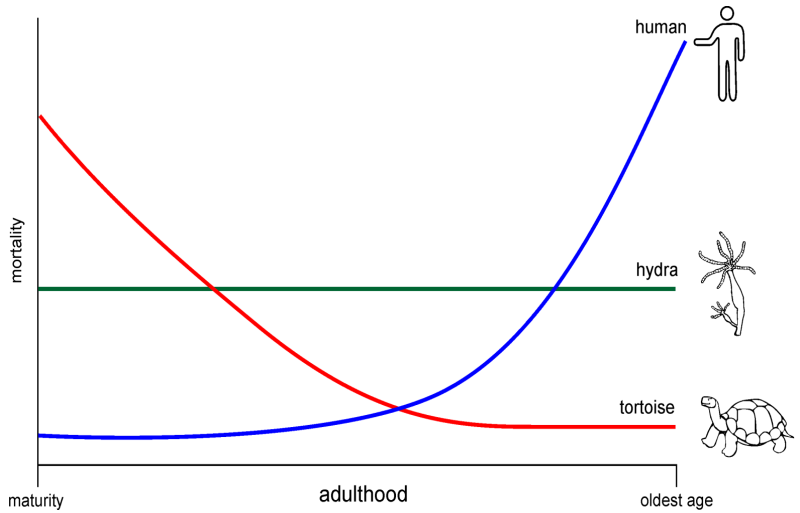
Interdisciplinary Centre on Population Dynamics,

University of Southern Denmark, Odense, DK



CPop

SDU