How safe is safe enough? - the answer provided by the J-value

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J-value website:
http://www.jvalue.co.uk/

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Summary

The lecture will:

• Clarify what we mean by "saving a life".
• Explain why life expectancy is a key parameter.
• Introduce the J-value.
• Explain the life quality index
• Define the J-value.
• Show how we can say when sufficient safety has been achieved
• Demonstrate that the J-value has been validated in 3 different ways.
• Illustrate briefly previous applications of the J-value.
• Present some conclusions
**Prelude:** To judge how much to spend on safety, we need to put a value on human life. But what do we mean by human life in this context?

Q. What benefit is conferred when a safety measure "saves" a person's life?

A. The benefit is the restoration of that person's life to come.
• **Problem**: we cannot predict how long anyone is going to live.

• **BUT** actuarial tables give us the **expected life to come** for a person of a **given age** and a **given gender**.

### Historic Interim Life Tables, United Kingdom

**Period expectation of life**
Based on data for the years 2005-2007

<table>
<thead>
<tr>
<th>Age</th>
<th>Males</th>
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<tbody>
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<td></td>
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<td>15</td>
<td>0.000254</td>
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</table>
Life expectancy rather than life-to-come

- **Life-to-come** for any individual is a random variable and so cannot be predicted.
- It is thus **life expectancy** that we may reasonably choose to value – the average life to come for someone of a given age and gender.
- We can then find an **average life expectancy** in the population to be protected.
Q. How do you place a value on life expectancy?

A. By using the J-value.
The J-value's principal assumption:

• Everyone attempts to improve his/her **quality of life**.
  • Certainly, no-one wants his/her quality of life to fall.

*So how do you define quality of life?*
Defining the Life-Quality Index*, Q

*It is assumed that a person's quality of life is forward looking and so will depend on what happens from now on*

Life quality for an individual is postulated to be based on:

1. how long he/she is expected to live from this point onwards.
2. how much money he/she will have to spend each year from now on.

* Jatin Nathwani, Niels Lind, and Mahesh Pandey, University of Waterloo, Canada, 1997. Also prior discussion with Ernest Siddall (AEC)
• **Life expectancy** can be found for the individuals of different ages from actuarial tables, which give life expectancy, $X(a)$, as a function of current age.

• An average value, $X$, of life expectancy for the population to be protected may be found.

• As a matter of equity, the next day of life for each person in the same jurisdiction or nation, old or young, rich or poor, is equally important.

• Choosing gross domestic product per head, $G$, as the income allows this equity to be achieved.

• So the variables determining life equality are $X$ and $G$
The Life Quality Index, $Q$

- Very general considerations lead to the life quality index taking the form:

$$Q = G^{1-\varepsilon} X$$

where $G$ is the income per head, normally taken to be the GDP per head

$X$ is the average life expectancy of the population being protected

$\varepsilon$ is the average risk-aversion of the population
General derivation of the Life Quality Index

An average individual's quality of life, $Q_1$, may be modelled as a function of income, $G$, and expected life from now on, $X$, in an analogous way to the dimensional analysis of pumps:

$$Q_1 = \alpha_1 G^\beta X^\gamma \quad \alpha_1 > 0$$

$$\Rightarrow Q_2 = Q_1^{\frac{1}{\gamma}} = \alpha_1^{\frac{1}{\gamma}} G^{\frac{\beta}{\gamma}} X = \alpha_2 G^{\frac{\beta}{\gamma}} X$$

$$\Rightarrow Q = G^{\frac{\beta}{\gamma}} X$$

This is, in fact, a standard Cobb-Douglas utility function, which can be developed into the Life Quality Index:

$$Q = G^{1-\varepsilon} X$$

where $X$ is the life expectancy and $\varepsilon = 1 - \frac{\beta}{\gamma}$ is the risk-aversion.
The term, $G^1 - \varepsilon$

- The term, $G^1 - \varepsilon$, is well known to economists as the **utility of income**
- $G^1 - \varepsilon$ denotes the usefulness of income, the **satisfaction** that income brings about.
- The **first increments of income** are hugely important, bringing **food, clothes and shelter**.
- **Later increments** of income bring progressively less satisfaction – the 3rd **Ferrari** matters less.
Typical utility curve

Utility, $u(G)$

GDP per head, $G$ (USD per y)
\[ Q = G^{1-\varepsilon}X \]

- The life quality index emerges as the sum total of the all the utility the average person can expect to gain over the rest of his/her life.
- This outcome of the analysis is intuitively satisfying.
Balancing Q when money is spent on safety

Life quality is maintained when

$$\frac{\delta Q}{Q} = 0$$

$$= \frac{\delta X}{X} + (1 - \varepsilon) \frac{\delta G}{G}$$

which calls for a balance between extra life expectancy, $\delta X$, gained and the disposable income, $\delta G$, given up to pay for the gain.
The J-value

- The Judgement- or J-value is simply the ratio of the amount actually spent on protection to the maximum that is reasonable (defined by $\delta Q = 0$):
  $$J = \frac{\hat{\delta}G}{\delta G}$$

- Hence $J = 1.0$ corresponds to the limiting condition where the actual expenditure on protection is justified by the gain in life expectancy.
- $J = 2.0$ implies overspending by a factor of 2: don't do it or find another way.
- $J = 0.6$ implies good value for money.
- No action is recommended below a de minimis level – about £1 per person, equivalent to about 5 minutes' extra life.
Validating the J-value: 1. against pan-national data The Preston Curve (Samuel H. Preston 1975)
Modelling the "Bristol curve" using the J-value

Assumptions:

• spending on safety measures occurs at a J-value of unity
• risk-aversion is the same for all nations in the world
• the net discount rate is same for all nations in the world
Validation of the J-value against pan-national data: the "Bristol curve"

Log (ave. life expectancy) vs. log (GDP per head)
for 180 nations in 2009

$R^2 = 0.6$ for 180 nations

18 outliers (marked with crosses) were excluded from the final fit.

$R^2 = 0.8$ for 162 nations
Outliers

- Afghanistan
- Angola
- Botswana
- Cameroon
- Chad
- Congo
- Cote d’Ivoire
- **Equatorial Guinea**
- Eritrea
- Gabon
- Guinea-Bissau
- Lesotho
- Malawi
- Namibia
- **Nicaragua**
- South Africa
- Swaziland
- Zambia
Conclusions from the validation exercise

• The J-value explains the major components of the Bristol curve

• The net discount rate is zero: do not discount life expectancy.

• About 80% of the variation in log life expectancy is explained by the variation in log GDP per head

• The J-value has been validated as a model of the way most safety decisions are taken throughout the world.
2\textsuperscript{nd} validation exercise

- Using data on increasing GDP per head to predict, for the UK, the combined genders' life expectancy at birth 20 years later to within 3 months.
J-value prediction of UK increase in life expectancy 1985 to 2005

<table>
<thead>
<tr>
<th></th>
<th>1985</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP/ head ($PPP)</td>
<td>21337</td>
<td>34623</td>
</tr>
<tr>
<td>Life expectancy at birth - actual (y)</td>
<td>74.59</td>
<td>79.02</td>
</tr>
<tr>
<td>Life expectancy at birth - J-value (y)</td>
<td>74.59</td>
<td>78.77</td>
</tr>
</tbody>
</table>

3rd validation exercise

• Predicting the life expectancy at birth in 20 years' time for 35 industrialized countries.
Comparison of J-value predictions with those of Bayesian averaging of 21 demographic models
Use of the J-value: examples

• The J-value has been applied to judge engineered options and safety measures, from trains to emission control systems to pharmaceutical efficacy.

• Extensive engineering optioneering has been carried out for MoD's nuclear propulsion programme.

• Application to evacuation and clean-up following a big nuclear accident.
Fukushima Daiichi nuclear accident

- 11 March, 2011
- Caused by the tsunami following the Great Tohoku Earthquake, 80 miles offshore and of magnitude 9.0
- 18,500 deaths caused by the tsunami, half of them over 65 year olds
- No immediate radiation deaths following the nuclear accident
Principal policy response after Fukushima: mass relocation

• **111,000** people told to leave their homes within the first few days.
• **49,000** people self-evacuated.
• Total: **160,000** people
• **85,000** people had not returned to their homes after 5 years.
• Premature deaths among old people moved out: **1121 early deaths** after 2 years, **1656** after 3 years, **2202** after 7 years.

Evacuation zone in Namie, Fukushima Prefecture, 2016
Increase in life expectancy from moving away from Fukushima Daiichi

- The 16,000 inhabitants of Tomioka Town faced the highest radiation dose, 51 mSv in year 1.
- This will have fallen to the Japanese Government's safe-return annual dose of 20 mSv in about 6 years – March 2017.
- Some villages, such as Naraha Town (original pop. 7,700), 1st year dose 7 mSv, have been declared "open" since 2015. Only 1500 had returned to Naraha by April 2017.

People in Tomioka would have gained just under 3 months life expectancy by relocating for 6 years.

The residual dose, starting at 20 mSv and decaying over 70 years will cost them a further 2 – 3 months.
The J-value recommendation on relocation after Fukushima

• The J-value showed it was not justified to relocate those living in the worst-affected town of Tomioka. Hence the relocation of the other 144,000 people could not be recommended either.

• For comparison, the life expectancy lost by residents of Tomioka by staying in their homes would have been less than the 4½ months that Londoners are currently losing to air pollution.

• (The study noted the additional factors reported by the World Health Organisation:
  • the trauma and disruption associated with mass relocation and
  • the survivors' perception that they were doomed, leading to excessively risky behaviour.
  • These factors militate further against relocation, but were not taken into account in the J-value analysis)
Urban Remediation:
Applying the J-value to urban decontamination after Fukushima

- Decontamination of 110,000 houses in Fukushima City
- Estimated dose reduction: 6 mSv in year 1, with continuing further falls
- Loss of life expectancy averted: 15 days
- Cost of clean-up: $370M
- J-value recommendation: very good value for money
Conclusions

- "Saving a life" actually means restoring a person's life to come to what it would have been without the hazard.
- Life expectancy is our best estimate of life to come.
- The J-value is the ratio of what you are spending or you intend spending to the maximum you should spend on safety.
- The J-value is objective.
- The J-value has been validated in 3 different ways against the way people take life extending decisions all over the world.
- The J-value tells you clearly when to stop spending on safety.
- The J-value has shown the radiation damage even after the biggest nuclear accidents is likely to be limited even without relocation.
- Only the J-value can put all safety risks from all sources on the same, level playing field.