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A COMPOUND INDEX OF NATIONAL DEVELOPMENT

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ABSTRACT. The Life Product Index (LPI) is a combination of life expectancy and gross domestic product. It is structured to the notion of 'quality-adjusted life' and calibrated to conform with the value of economic activity reflected in the national time budget. The LPI can serve as a guide in national policy planning. It can also be used as an indicator of sensible regulation of hazardous technology and as a guide in the assessment of individual projects. An LPI criterion for net benefit assessment of a project, policy or proposed regulation is derived from first principles. Application is illustrated by an example.

1. INTRODUCTION

The gross domestic product per person has been used for decades as an indicator of national progress. This use has pushed national policy narrowly towards economic growth, to the detriment of other aspects of development such as education, health or welfare. Economic growth is only instrumental, necessary but not sufficient to ensure better conditions of life, instrumental to social well-being. The displacement of the GDP from principal to supporting actor is justified. But what should replace it in its role of social index? This paper describes an index for consideration among the candidates.

Decision makers in government and industry are responsible that public resources are distributed among the various major budget items in a way that is truly in the public interest. Comparison of benefits with risks is necessary for any project or policy that has a bearing on health or safety. This social accounting requires a general framework for assessment to help the decision maker be consistent and accountable. Assessment of any major project from the viewpoint of the public interest ought to be guided by systematic quantitative evaluation. All detrimental effects of technology must be quantified to be balanced against the beneficial effects. Accounting of the benefits and the detriments can become the basis for open transparent assessment of the

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major impacts. It would be desirable to relate social indices to the individual policy decisions faced by government.

The GDP is the prime macroscopic measure in public accounting. Still, it cannot be considered as a 'social' index if those who produce the wealth cannot see it all spent, on the whole, according to their wishes. If the GDP goes largely to service external debt on capital, is exported to safer havens, or used to build "prestige" facilities of little utility, then the GDP is a poor indicator of the people's "command over resources needed for a decent living". Some nations cannot be ranked credibly by GDP or by an index that has GDP as dominant component. But the real gross domestic product per person may be used to a first approximation as surrogate measure of the quality of life if the national budget has broad public consent and if all goods and service are brought to the market (no shortages, no rationing, no restrictions on travel, and so on).

Life expectancy may be used as the measure of overall life safety and the GDP per person as measure of the quality of life. These indicators in principle allow an approximate but quantitive treatment of the detriments and the benefits that arise from the use of technology. The detrimental effects contribute primarily to a loss of life expectancy. Other potential losses, such as the risk of environmental harm, can often be drawn into account in terms of the work necessary to compensate them. The beneficial effects, both direct and indirect, result in a gain in life expectancy.

These two basic measures, life expectancy and real gross domestic product per person, can be refined further. Some improvements to the basic indicators are discussed below. Still, as they stand, they provide together a reliable measure of two important aspects of social conditions in a nation, a province or other social group: (1) the command over resources to satisfy needs and wants and (2) the time to enjoy it. They reveal with some validity the changes in social well-being. Also, sufficient data and knowledge are available to assess these measures. The life product index proposed in this paper is derived from these two indicators, uniquely satisfying two simple mathematical requirements that express invariance and self-consistency.

A Human Development Index (HDI) was proposed by the United Nations Development Programme as an indicator of social well-being. The HDI is intended "to reflect the fact that development enlarges people's choices" (UNDP 1990). The HDI is composed of three basic indicators, (1) *life expectancy at birth* that serves to quantify longevity, (2) *literacy*, quantified by the adult literacy rate, standing for the access to information and knowledge, and (3) *command over resources* needed for a decent living, expressed by a logarithm of the purchasing-power parity GDP per person up to a maximum of $$ 4 832 ($$ = purchasing-power of 1 US$ in 1987). To compute the HDI, the UNDP calculated the range of each basic index for all (130) nations in the study and determined the relative score for each country. The HDI of the country is the arithmetic mean of these three scores. Table I lists the HDI and the basic indicators for some of the 130 nations considered by the UNDP (1990). For a more detailed analysis of the HDI see (Lind, 1992).

While the HDI has many similarities to the life product index (LPI) of this paper, there is an important difference. The HDI was apparently composed by judgment, but more or less arbitrarily. The LPI is derived mathematically from two fundamental postulates, and its parameter is calibrated to an observed time budget. The LPI is also broader in its intended field of application. Like the HDI, it can serve to rank nations according to social development and help to indicate desirable directions overall for future development. But the LPI is intended as a tool in the administration of health and safety, in the assessment of regulations or individual major projects, or as an aid to setting economic policy.

Efforts to develop quantitative indicators of social well-being began in the 1950s (UN, 1954, 1961; OECD, 1977, 1982) and is still ongoing. The *quality-adjusted life year (QALY)* was advocated as a significant unit of measure. Zeckhauser and Shepard (1976) suggested that the benefit of health and safety provisions should be measured in quality adjusted life-years saved. Vaupel (1976) used this idea to assess the "death problem" in the United States. He argued that there should be greater emphasis on prolonging life by reducing the incidence of premature death, showing that it would be greatly beneficial to reduce the incidence of early death even if only by a few per cent.

Similarly, the OECD social indicator development programme (OECD, 1977) made a distinction between length of life and length of healthy life. The length of life can be easily assessed. Healthfulness

TABLE I
Human Development Index 1990 and Life Product Index 1987

(A) Country:		(B) LE '87	(C) AL '87	(D) RGDP $$	(E) HDI '87	(F) LPI '87
1	Niger	45	15	452	0.11	0.32
4	Sierra Leone	42[a]	32	480	0.16	0.30
7	Somalia	46	13[a]	1000	0.20	0.38
20	Zaïre	53	65	220	0.30	0.34
23	Bangladesh	52	34	883	0.32	0.42
24	Nigeria	51	45	668	0.33	0.39
36	Pakistan	58	31	1585	0.43	0.51
37	India	59	44	1053	0.45	0.49
42	Kenya	59	64	794	0.49	0.46
54	Indonesia	57	77	1660	0.60	0.51
66	China	70	70	2124	0.72	0.65
80	Brazil	65	80	4307	0.79	0.68
90	Romania	71	96	3000	0.87	0.70
91	Mexico	69	92	4624	0.89	0.73
95	Portugal	74	87	5597	0.92	0.80
105	U.S.S.R.	70	99[a]	6000	0.93	0.77
109	Greece	76	94	5500	0.96	0.82
111	Israel	76	96	9182	0.97	0.90
112	U.S.A.	76	96	17615	0.97	1.00
117	Italy	76	97	10682	0.98	0.92
122	Denmark	76	99[a]	15119	0.98	0.98
123	France	76	99[a]	13961	0.98	0.96
124	Australia	76	99[a]	11782	0.98	0.94
126	Canada	77	99[a]	16375	0.99	1.00
128	Switzerland	77	99[a]	15403	0.99	0.99
129	Sweden	77	99[a]	13780	0.99	0.97
130	Japan	78[a]	99[a]	13135	1.00	0.98

(A) Rank among 130 nations according to HDI, after UNDP (1990)
(B) Life expectancy at birth, years (UNDP, 1990)
(C) Adult literacy, % extrapolated linearly from 1975 and 1985 data according to UNDP (1990)
(D) Real Gross Domestic Product, purchasing power parity in 1987 U. S. dollars.
(E) Human Development Index (UNDP, 1990)
(F) Life Product Index 1987 = $(D)^{1/6}$* (B), normalized: USA 1987 = 1.00
(a) Extreme high or low values in (UNDP, 1990) over 130 nations.

distinguishes between different degrees of impairment during this time. Efforts to measure quality of life in various states of health are continuing.

A quality-adjusted life expectancy could be used as objective function when policy or projects for health and safety must be selected from a fixed budget allocation to serve the public interest. Unfortunately a quality-adjusted life expectancy indicator is not yet available. The LPI suggested in this paper could serve as a simple surrogate for quality-adjusted life expectancy.

Disease and accident strike at random. It follows that the allocation of society's scarce resources to health and safety, when wisely distributed over the many hazards, produces the greatest total increase in life expectancy in good health in the society. This distribution results in the greatest expected benefit to all for any given allocation.

The benefits of a safety measure can, as a first approximation, be expressed (in person years) as the gain or increase in life expectancy in good health. For the present, there are advantages to using simple life expectancy as a surrogate measure for safety. The main advantages are availability and reliability. Life expectancy is also better than simpler measures, such as crude death rates; it is not influenced by the age-specific composition of any particular population, allowing direct comparison of trends over time and among countries or groups.

It is not enough to have good but separate indicators of the benefits of health and safety provisions. For optimum management of health and safety it is necessary to weigh the benefits against the costs, and so they must somehow be expressed in similar units of measurement. In spite of many efforts there is as yet no broadly accepted way to do this, because our culture proscribes expression of the value of life in economic terms.

One way to overcome this taboo is to use life itself as the *numéraire*: 'man is the measure of all things'. Thoreau wrote: "The value of a thing is the amount of what I will call life you are willing to give in exchange for it, now or in the long run". This idea, akin to the labor theory of value, has been used to derive a life-money equivalent (Lind, 1977, 1989). Thus, a life time efficiency measure can be attached to any project, regulation, or policy, collectively called *prospects*. The *life time efficiency* (*LTE*) of a prospect is the ratio of the expected life time gained to the time consumed in implementation. If, in particular, the LTE is equated to unity it will yield a quantity that loosely can be called the "value of a life" (Lind, 1989).

The present paper circumvents the value-of-life problem in a different way, avoiding the need to define an economic equivalent of life when co-assessing risk and benefit of a prospect. Briefly, improving health or safety improves the life expectancy in good health, while economic benefit improves the GDP per person. Both, alone or together, should improve the LPI. A prospect is favorable if, and only if, the two in combination have a net positive effect on the LPI.

The next section derives the life product index (LPI), a compound index that may be considered to reflect quality-adjusted life expectancy for a group of people. The LPI is the function $b^w e$ of the real gross domestic product per person per year, b, the proportion of time budgeted to economic activity, w, and the life expectancy at birth, e. The life product may serve as a measure of benefit to the public.

The parameter w is a reflection of the value placed on a reduction of mortality in terms of economic expenditure. Section 5 illustrates how the LPI may be used in project assessment.

2. THE LIFE PRODUCT INDEX

The real gross domestic product per person, b, and the life expectancy at birth, e, both reflect important aspects of what is meant by the 'general well-being' in a society. Both are readily available, reliable and accurate. It is of interest to examine the compound indicators that can be formed from the two.

One way to look at it is to consider b as a measure of the average share of the production of wealth, available to be spent on whatever adds the most to the enjoyment of life. The life expectancy of a person, e, or rather some continuous monotonic function $h(e)$ of e, is then an appropriate factor to apply to b to account for the duration of that enjoyment. Differences between groups of people in the mean fraction of life spent in good health (without which the enjoyment of b is curtailed) are neglected.

Alternatively, the enjoyment of life may be thought of as having two dimensions, duration and intensity. If the duration is measured by e, then a function of b, $f(b)$, can serve as weighting factor to express the enjoyment that the average person can expect from a life spent in that society. Any product of the form $P = f(b)h(e)$ therefore is a possible compound social indicator. The factor $f(b)$ represents the intensity and the factor $h(e)$ the duration of the enjoyment of the average life. Such products are candidates to serve as a quantitative expression of the idea of "quality-adjusted life expectancy".

For each nation or region, e and b are functions of time, t:

$$e = e(t), \qquad b = b(t). \tag{1}$$

The (b, e)-family of aggregated indicators may be written as

$$P = f(b)h(e). \tag{2}$$

A project, undertaking or policy will have respective expected impacts $\mathrm{d}b$ on b and $\mathrm{d}b$ on e that may be assumed infinitesimal. Differentiation and some algebra give the expected impact $\mathrm{d}P$ on P:

$$\mathrm{d}P/P = (bf_b/f)\,\mathrm{d}b/b + (eh_e/h)\,\mathrm{d}e/e, \tag{3}$$

in which partial derivatives are shown by subscript. The ratio of the two coefficients in parentheses in (3) may be interpreted as the economic equivalent of a small relative increase in life expectancy, or as the life equivalent of a unit of relative increase of b, depending on which of the two is taken as the denominator. If this ratio is to be a constant — which is a sensible constraint to impose on the compound index — each factor in parentheses in (3) must be constant:

$$bf_b/f = \text{const.};\; eh_e/h = \text{const.} \tag{4}$$

Solution of (4) yields

$$P = b^p e^q, \tag{5}$$

in which p and q are constants. Without loss of generality q may be taken as unity, giving the index

$$P = b^p e \tag{6}$$

called a life product. Correspondingly

$$\mathrm{d}P/P = p\,\mathrm{d}b/b + \mathrm{d}e/e. \tag{7}$$

3. CALIBRATION

Parameter p may be calibrated such that the life product reflects the relative value of time and wealth in a society. The constant p may be estimated from the average time budget in a society in the following manner. In North America the "average person" works about 50 years out of 80 years of life; works some 48 weeks per year out of 52; and works about 42 hours per week (including time spent travelling to and from work) out of 168. Work thus consumes roughly the proportion

$$w = (50/80)\,(48/52)\,(42/168)\,(100\%) = 14\%$$

of the average person's life nowadays in North America. The balance, $1 - w = 86\%$, is non-work time. A recent social survey by Statistics Canada found that the entire Canadian population spends 3.6 hours (15%) out of 24 on paid work and education, in good agreement with the present estimate (Harvey *et al.*, 1991).

It is noted that many people consider a certain minimum time for each person as necessarily budgeted for sleep and eating, as physiological necessity. Suppose that this minimum totals one third of the time available. Then it can be argued that work consumes the fraction (3/2) (14%) = 21% of the time "really" available. However, time spent eating or sleeping is neither more nor less valuable to a person than other non-work time, because some portion of it can freely be reallocated until the marginal returns on all activities, whichever way they are labelled, are equal.

The time spent at work (together with invested capital) produces the average person's share of the GDP. In addition, it produces some work satisfaction, which is difficult to define in comparable terms. Most work in this world is hard, repetitive, dull, dangerous or otherwise uncomfortable, and little work would get done if it were not for economic benefit. As a first approximation the non-financial returns of work may be ignored.

Admittedly, some people — many artists and scientists, for example — receive more direct satisfaction from their work than indirect satisfaction through remuneration. Their gross income is a relatively unimportant part of the total benefit received from working. If a person derives some satisfaction from work, then the fraction w of the life spent in economic production is reduced in the proportion (economic benefit)/(economic benefit + satisfaction from work). Suppose that the 'average person' largely works for economic benefit; the gross pay represents a quantifiable fraction, perhaps 75% ± 20%, of the total benefit, the rest being "satisfaction". Since the average person thus freely converts roughly 14% of a year of life into $b/0.75$, one small amount of time dt years is worth (at most) $b\ dt/0.75/0.14 = b\ dt/0.10$. On the other hand, if time on the average were worth much less than the yearly rate of $b/0.10$, people would willingly spend it doing overtime work. Thus, w = (75%) (14%) = 10% approx. for a developed society.

Consider for comparison a less fortunate society in which the average person must work for 40 out of an expected 50 years of life, must work 51 out of 52 weeks when employed (but is unemployed or severely underemployed 30% of the time), works 60 hours a week including travel time, and receives no satisfaction from work. For such a society similar calculations give $w = (40/50)\ (51/52)\ (70\%)\ (60/168) = 0.20$ on the basis of a 24-hour day. Thus, w is not very sensitive to the degree of development of a society. Moreover, as shown below, the life product is very insensitive to the value of w when it is normalized with respect to a particular country and year.

There is a simple relationship between parameter p and the observable quantity w. There are two different ways people can add to their expected discretionary time. One way is to improve the life expectancy; adding a proportion $de/e = r\%$ to the life expectancy increases the discretionary time by $r/(1 - w)$ %. The other way is to work less; increasing life expectancy by $r/(1 - w)$ % in this way requires that work time be reduced by $r/w\%$.

The marginal value of time is of interest here, so it is necessary to consider what fraction of b would be produced by decreasing the time allocated to work by a small amount dt. The simplest assumption is that the lost production is proportional to the time of production, equal to $b\ dt$. However, there is a reason that the lost production would be somewhat higher: it would be produced with the same capital except to compensate for reduced wear. On the other hand, diminishing returns would offset the difference; it is therefore concluded that the relative reduction in the GDP, db/b, is equal to r/w %. Equation (19) then gives break-even, $dP = 0$, when $-rp/w + r = 0$, from which $p = w$. This yields the proposed *Life Product Index* (*LPI*) $\equiv P$,

$$P = b^{w}e \tag{8}$$

and (7) gives the differential expression

$$\mathrm{d}P/P = w\,\mathrm{d}b/b + \mathrm{d}e/e. \tag{9}$$

Column (F) in Table I shows the value of the life product index for 1987 for a selection of countries, which includes about 70% of the World population, based on $w = 1/6$. Table I shows that the life product may not be an unreasonable indicator of the aggregate "quality-adjusted life expectancy" in a country.

Table II serves to show that it is not important to know w with great accuracy. Once the life product is normalized with respect to a par-

TABLE II
LPI-Ranking of 27 Countries according to HDI and LPI-Type Criteria

(A) HDI Rank /130		(B) LE '87	(C) RGDP $$	(D) LPI-Type Indices: $w = 1/4$	(E) 1/6	(F) 1/10	(G) HDI	(H) Rank according to (D)	(E)	(F)	(G) HDI
126	Canada	77	16375	0.99	1.00	1.00	1.00	2	1	1	4
112	U.S.A.	76	17615	1.00	1.00	1.00	0.99	1	2	2	9
128	Switzerland	77	15403	0.98	0.99	0.99	0.99	3	3	3	3
130	Japan	78	13135	0.95	0.98	0.99	0.99	4	5	4	1
122	Denmark	76	15119	0.96	0.98	0.98	0.98	5	4	6	7
129	Sweden	77	13780	0.95	0.97	0.98	0.98	6	6	5	2
123	France	76	13961	0.94	0.96	0.97	0.97	7	7	7	6
124	Australia	76	11782	0.90	0.94	0.95	0.95	8	8	8	5
117	Italy	76	10682	0.88	0.92	0.94	0.94	9	9	9	8
111	Israel	76	9182	0.85	0.90	0.92	0.93	10	10	10	10
109	Greece	76	5500	0.75	0.82	0.86	0.88	11	11	11	11
95	Portugal	74	5597	0.73	0.80	0.84	0.86	12	12	12	13
105	U.S.S.R.	70	6000	0.70	0.77	0.80	0.82	13	13	13	12
91	Mexico	69	4624	0.65	0.73	0.77	0.79	14	14	14	14
90	Romania	71	3000	0.60	0.70	0.75	0.78	15	16	15	15
80	Brazil	65	4307	0.60	0.68	0.72	0.74	16	15	16	16
66	China	70	2124	0.54	0.65	0.71	0.74	17	17	17	17
36	Pakistan	58	1585	0.42	0.51	0.56	0.60	18	18	18	21
54	Indonesia	57	1660	0.42	0.51	0.56	0.59	19	19	19	18
37	India	59	1053	0.38	0.49	0.54	0.58	20	20	20	20
42	Kenya	59	794	0.36	0.46	0.53	0.57	21	21	21	19
23	Bangladesh	52	883	0.32	0.42	0.47	0.50	22	22	22	23
24	Nigeria	51	668	0.30	0.39	0.44	0.48	23	23	23	22
7	Somalia	46	1000	0.30	0.38	0.42	0.45	24	24	24	25
20	Zaire	53	220	0.23	0.34	0.40	0.45	25	26	25	24
1	Niger	45	452	0.24	0.32	0.37	0.41	26	25	26	27
4	S'ra Leone	42	480	0.22	0.30	0.35	0.38	27	27	27	26

ticular country and time, there is little difference between the LPI values and the rankings by LPI between the two extremes $w = 1/4$ and $w = 1/10$. Accurate knowledge of w is also of little importance when comparing a nation or a group of people with itself at different times, but it can be important in the evaluation of policy or projects.

4. JUSTIFICATION OF A PRACTICE

Equation (9) may be used to assess whether a prospect (i.e. project, or change of policy, regulations, rules or practices) confers a positive net benefit in comparison with an alternative that can be labelled *status quo*. If *net benefit* is defined as an increase in the life Product $P = b^w e$ over status quo, then the net benefit $\mathrm{d}P$ in (9) will be positive if and only if

$$\mathrm{d}b/b + (1/w)\,\mathrm{d}e/e > 0. \tag{10}$$

In application of (10) at least one of the terms on the left hand side would be positive, but either term may be negative.

5. MORTALITY

Difficulties in application are mainly connected with the term $\mathrm{d}e$. Practical analysis of policy or projects requires that the change in life expectancy, $\mathrm{d}e$, be estimated from the more conventional measures of death risk. For many undertakings it is possible to estimate the loss of life, from which the increase in mortality over the alternative for a given group of persons can be estimated. Crude mortality is a useful measure, in spite of its known imperfections, because it is available and accurate. The reduction in life expectancy due to an increment in crude mortality can be estimated either analytically or empirically, as explained below.

Analytically, suppose that the mortality of a cohort having remaining life expectancy e_r is changed by some health or safety intervention. If the crude mortality rate, M, is changed by the factor $\mathrm{d}M/M$, then the cohort life expectancy e_r changes in proportion. This adds $(\mathrm{d}M/M)e_r$ years to the life expectancy at birth, which therefore increases by the proportion $(\mathrm{d}M/M)\,(e_r/e)$. Thus

$$\mathrm{d}e = -\mathrm{d}M/(M/e_r) = -\mathrm{d}M/k^* \tag{11}$$

holds as an approximation. In (11) dM is the net increase in mortality (units: deaths/person/yr) associated with the intervention. If the intervention is an improvement in safety, then dM is negative. More generally, if an intervention affects the life expectancy of different age groups, then e_r is an appropriate average for the whole. So, k^* equals (e/e_r) (M/e); for Canada and the USA this amounts to at least (0.01/yr)/(77 yr) = 0.00014 deaths/yr/person/yr (for hazards that apply to the very young).

Empirically, Schwing (1979) has examined human life tables (Preston *et al.*, 1972), considering the effects if different specific causes of death were eliminated. Schwing observed a simple relation between the impacts on the change in gross mortality (expressed in yearly deaths per 100 000 population) and the life expectancy at birth: The crude mortality rate of each cause is approximately equal to 50/100 000 times the years of increase in longevity if each category of death could be eliminated. Thus

$$\mathrm{d}e = -\mathrm{d}M/k \tag{12}$$

holds as an approximation. In (12) dM is the net increase in mortality (units: deaths/person/yr) associated with the change. k may be called *Schwing's constant*, equal to about 0.0005 deaths/yr/person/yr.

The condition that an undertaking contributes positively to the LPI is then the *life product criterion*

$$\mathrm{d}b/b - \mathrm{d}M/M^* > 0 \tag{13}$$

in which M^* is the quantity

$$\begin{aligned} M^* &= kew \\ &= (0.0005 \text{ deaths/person/yr}^2)\,(77 \text{ yr})\,(0.10) \\ &= 0.0038 \text{ deaths/person/yr.} \end{aligned} \tag{14}$$

This value of M^* is in good agreement with the analytical estimate; the two are equal for $e_r/e = 3/8$, corresponding to about 50 years of age.

M^* is specific for each nation or group at a particular time, but it may be taken as constant without serious loss of accuracy, as (14) shows. Use of the life product criterion is illustrated in Section 7.

6. VALIDITY OF THE LIFE PRODUCT INDEX

Four aspects of validity are of interest here, called criterion-related validity, construct validity, content validity and discriminant validity (Zeller and Carmines, 1980). These are briefly considered in turn.

A quantity has *criterion-related validity* if it has significant correlation with some other relevant measure. Any life product of the form $b^p e^q$, where b and e are positive and positively correlated quantities and p and q are constants, has criterion-related validity if both b and e have criterion-related validity. To show this, let b_1 and e_1 denote the other relevant measures to which b and e respectively have significant positive correlation, and consider the measure $b_1{}^q e_1^p$. The corresponding life product is significantly correlated to this measure and will therefore have criterion-related validity.

A measure has *construct validity* if it has significant correlation with some other theoretically relevant measures. Again, suppose that b and e are positively correlated, that they are theoretically relevant, and that both have construct validity. Then any life index of the form $b^p e^q$ will be significantly correlated with both b and e and will thus have construct validity.

A measure has *content validity* to the extent that it adequately or completely refers to the relevant content of some area or domain to be measured. This attribute is a matter for the potential user to define. The domain here is the "public interest". If we agree that it is a meaningful concept, and that it exists, and further agree that there is adequate consensus that longevity, good health, and wealth are good and relevant to the public interest, then there should be adequate consensus that the life product index $b^w e$ has content validity.

Finally, a quantity had *discriminant validity* if it can discriminate between individuals in a random or exhaustive sample on the basis of their having or not having the attribute supposedly being measured. No claim can be made that the life product index is a measure of anything other than itself. It is merely claimed to be *of interest* in connection with questions such as "To what extent is the public good being advanced in this nation?". For any value of w it discriminates clearly, consistently and accurately between the nations listed in Table I, so it is predicted that with more recent data, when it becomes available, the LPI will discriminate well.

7. DISCUSSION

This paper has shown that a *life product index* can be derived as a function of three well-known basic social indicators: the real gross domestic product per person, b, the proportion of their lives people spend on economic activity, w, and the life expectancy at birth, e. These basic indicators are widely available and accurate, and a case has been made that the compound life product index $b^w e$ has validity and resembles the intuitive concept of 'quality-adjusted life expectancy'. The associated *life product criterion* may be used as a guide to judge whether a policy or a project is in the public interest.

The life product $b^w e$ is a time series for any group of households. The value $w = 0.1$ seems appropriate for many contemporary developed societies. More detailed historical study of the time budget of nations or groups within nations may reveal more appropriate values of the parameter w.

While an accurate value of w is unnecessary when ranking nations or when charting a nation's progress in time, it is important that the component index be adjusted for purchasing power of a monetary unit. Within a country this means compensating for the rate of interest and inflation.

Like any other social or psychological indicator (e.g. the intelligence quotient IQ), the life product cannot be proven to indicate any attribute that has an established meaning in ordinary language (such as 'intelligence'). The life product is a measure only of itself. However, like the GDP or the IQ, it may acquire some legitimacy through use. It derives its validity from the constituent social indicators, the gross domestic product per person and the life expectancy at birth.

The life product is easy to calculate and, as shown in Table I, it discriminates between nations in a way that would not disagree with intuition. It can be used to monitor progress of welfare in a society. The associated life product criterion of positive net social benefit, (13), is not difficult to apply in practice, as illustrated in Section 8.

Maximizing the quality-adjusted life expectancy is a sensible societal goal, and the life product is a reasonable measure of this concept. Nevertheless, this does not suggest that a particular and inflexible set of values be imposed on the co-assessment of risks and benefits. Since the composition of quality-adjusted life expectancy is not specified in terms of measurable quantities (indicators), its appropriateness – and that of the LPI – cannot be discussed. In the manner of multi-valued optimization theory it is possible to imagine a vector-valued (or multi-component) indicator. The LPI may be one component thereof.

The life expectancy at birth integrates age-specific mortality across all ages. It is an excellent and accurate measure of the total mortality of a nation, filtering out such factors as age distribution and sex distribution of the population. The life expectancy at birth has some minor shortcomings as a component of a social index. It may be considered as a practical surrogate for a truer estimator of healthy life duration.

A social index in effect defines 'development' to be any trend that increases the index. The index would set a target for nations to strive for. The presumption is that professionals with the index can tell the world what 'development' is. Behind an index is a theory of humanity: what the "good" life is and what we should strive for. The theory should be brought into the open and needs broad popular consent before it is used as a beacon.

8. EXAMPLE – A PETROCHEMICAL REACTOR COMPLEX

Suppose that a multinational corporation is proposing to locate a petrochemical facility in a country and has submitted an application to the government documenting the estimated impacts (Lind *et al.*, 1991). The government wants to assess whether or not the impact of the project is in the public interest. As part of this assessment it wants to evaluate the impact of the facility according to its impact on the life product index. Table III shows the analysis.

The government concedes that the project will likely bring some wealth to the nation (lines 10 and 18). This can be expected to improve the living standard and thus indirectly to increase the life expectancy, but they decide to credit the project with only 10% of this expected increase (line 22). The results of the analysis (line 26) indicates that the project is expected to have a positive influence on the LPI, lending support to approval of the project.

TABLE III
Projection of impacts of a chemical project (a hypothetical illustrative example)

A. Assessment of Risk		
(1)*	Net product of the facility	100 \$M/yr
(2)*	Interest and dividends on foreign capital	60
(3)	Net contribution to the GDP (1) − (2):	40 \$M/yr
(4)*	Less environmental cost (compensation)	10
(5)	Net monetarized benefit (3)—(4) $N =$	30 \$M/yr
(6)*	GDP =	\$ 36 000 \$M/yr
(7)*	Population:	12 M
(8)	GDP per person (6)/(7):	$b =$ \$ 3000/yr/person
(9)*	Life expectancy at birth:	$e = 66.67$ yr
(10)	Net benefit per person (5)/(7):	$\mathrm{d}b =$ \$ 2.50/yr/person
(11)*	Occupational risk in the plant per exposed person: Total for normal operation and accidental exposure:	= 12 per 100 000 deaths/yr/person = 0.00012 deaths/yr/person
(12)*	Number of exposed workers:	15000
(14)	Contribution to society's occupational risk (12) (13):	= 1.8 deaths/yr
(15)*	Analysed risk to the public:	0.6
(16)	Total risk (14) + (15):	2.4 deaths/yr
(17)	Total increased gross mortality (16)/(7) =	2E-7
B. Assessment of Benefits		
(18)	Project's share of GDP growth (3)/(6): $\mathrm{d}b/b =$	0.111%
(19)*	Expected rate of increase of life expectancy	= 0.6 months/yr = 0.05 yr/yr
(20)	Equivalent corresponding decrease in mortality	(19)/(9) = 0.00075
(21)	Project's share of (20), (18) (20):	0.0000008
(22)	Portion of (21) credited to project: 10% (21) =	8E-8
C. Assessment of Net Benefit		
(23)	Negative benefit of project (17)—(22): $\mathrm{d}M = 1.2\text{E-}7$ deaths/yr/person	
(24)	$M^* = 0.0038$ deaths/yr/person	
(25)	$\mathrm{d}M/M^* = (23)/(24) =$	0.0000315
(26)	Net benefit of project by LPI: (18)—(25)	0.108 % > 0

The net benefit is *positive* according to the LPI criterion.

* *Note*: Inputs to the analysis are marked with an asterisk.

In practice, extensive documentation would be required to substantiate all data entering the analysis, marked with an asterisk (*) in Table III. The entries are subject to uncertainty in varying degrees, which would propagate through the table and would be reflected in an uncertainty in the net benefit, line 26. This uncertainty is merely a technical detail that, however, would have to be taken into account in the project assessment.

9. CONCLUSIONS

Accountability in responsible government requires the development of quantitative social indicators that are relevant, accurate, reproducible, available, robust against falsification and able to discriminate performance. The Life Product Index (LPI) described in this paper is particularly relevant to developed nations or social groups in such countries. It is accurate, reproducible, available, and as robust against falsification as the national accounts are. It can discriminate and compare performance between nations at the same time or at different times. The LPI is derived analytically by a separation of variables and is calibrated to agree with time budget allocations to leisure and economic activity typical of developed nations.

The LPI is a compound indicator and purports to reflect one aspect of desirable development of a nation. Thus it reflects a relative value placed upon the two component indicators: Life expectancy and gross domestic product. Differential relationships arise from these relative valuations that reflect how a prospect (i.e. a project, programme, regulation, rule or code or other undertaking that marginally can influence the component indicators) contributes or detracts from the national interest according to the LPI. It has been shown how this permits the comparison of risks and benefits for an undertaking.

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