Sustainability Index: An Economics Perspective

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Abstract

The UN Commission on Sustainable Development is expected to release an updated set of sustainable development indicators in 2006. The need for a composite index has been emphasized in the literature, but due to data aggregation, ideological and other problems none of the presently available composite indices has gained universal acceptance. This paper takes a new approach in defining a sustainability index by using marginal human development and marginal damage cost as key decision variables. It also defines strong and weak sustainability conditions. In most cases, the proposed sustainability index is more restrictive than the financial cost-benefit analysis. A feasible project, based on cost-benefit analysis, may not be sustainable locally, regionally, nationally or internationally; and that can be a potential cause of intra-regional or international dispute. This paper defines the critical path of sustainable development. Simulations based on different values of the choice variables give a set of possible sustainable development trajectories. By incorporating social discount factor, risk and uncertainty premiums, the proposed methodology can accommodate a range of ideologies. The proposed index can be used for project evaluation as well as for determining the sustainability of current state of economic development in a country.

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1. Introduction

Among numerous definitions\textsuperscript{1} of sustainable development, the Bruntland Commission’s (1987) ‘very broad and non-specific’\textsuperscript{2} definition, meeting the basic needs of the present generation without compromising the ability of future generations to meet their needs, is often considered a benchmark definition. However, a sustainability condition should not restrict the present generation from meeting higher-order needs\textsuperscript{3} at the cost of natural and social environments,\textsuperscript{4} unless they pose any threat to future development. The challenging task for the policy makers, however, is to find the optimum level of development without risking future development potentials; or to find the optimum level of conservation with no unnecessary restraint on present development or well-being\textsuperscript{5} of the people.

A sustainable development policy-making is contingent upon ‘proper identification and measurement’\textsuperscript{6} of sustainable development indicators (SDI), but we are still far from defining a unique set of indicators.\textsuperscript{7} Though it’s a challenging endeavour, the integration of SDI into a single sustainability index (SI) or a set of sustainability conditions (SC) is essential for them to be used in a decision-rule for sustainability assessment. This paper uses a new methodology to integrate sustainability indicators into a single sustainability index, and it also defines a set of sustainability conditions.

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\textsuperscript{1} Pezzy (1989) cited more than fifty definitions of "sustainability." Cavalcanti (1996) in his Keynote Speech mentioned that about 57 definitions of sustainable development could be found.

\textsuperscript{2} Bartelmus (2001)

\textsuperscript{3} In Maslow’s (1968) framework, basic needs include material needs and social needs. Material needs refer to physiological needs, safety and security. Social needs include self-esteem, affection, acceptance, and so on. A higher-order or moral need may be love, justice, aesthetics, and so on.

\textsuperscript{4} Natural and social environments are defined in section 3 of this paper.

\textsuperscript{5} I do not make any distinction between welfare and well-being in this paper.

\textsuperscript{6} Dewan (1998)

\textsuperscript{7} Pinter, et al. (2005)
2. Indicators and Indices of Sustainability

For the past two decades, there have been many local, regional, state/provincial, national and international efforts to find useful sustainability indicators.\(^8\) The key feature of some of these suggested indicators is that they are defined through public participation. Therefore, these indicators are meaningful to the respective community. However, indicators based on asymmetric information and the heterogeneous interests of the stakeholders often make them incomparable, and therefore, less usable in other environments. International Institute for Sustainable Development (IISD) hosts and manages the compendium of sustainable development indicator initiatives around the world. Currently, the site has information about 669 initiatives.\(^9\)

The UN Commission on Sustainable Development (UNCSD) from its working list of 134 indicators derived a core set of 58 indicators for all countries to use.\(^10\) The CSD is currently updating this set of indicators. I believe that where possible, a universal set of indicators can be defined, but local sustainability concerns should be addressed in assessing the sustainability of an economic activity.\(^11\) We should work to find a mechanism that is flexible enough to incorporate these diverse sets of indicators,\(^12\) and yet give a comparable index.

Recent initiatives include the development of aggregate indices, headline indicators, goal-oriented-indicators, and green accounting systems.\(^13\) Early composite indices include Measure of Economic Welfare (MEW) by Nordhaus and Tobin (1973), Index of Social Progress (ISP) by Estes (1974), Physical Quality of Life Index (PQLI) by Morris (1979), and Economic Aspects of Welfare (EAW) by Zolotas (1981). Brekke (1997), however, challenges the concept of distinguishing economic welfare from non-economic welfare.

Indices developed in the 1990s to measure the aggregate performance of the economy or the sustainability include Human Development Index (HDI) by the UNDP

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\(^8\) For a comprehensive list, see the International Sustainability Indicators Network (2006).

\(^9\) IISD (2006)

\(^10\) UN Division for Sustainable Development (2005)

\(^11\) Meadows (1998) also emphasized the need for ‘overarching indicators’.

\(^12\) Indicator Zoo, by Pinter, et al. (2005), assumes that future SDI practices will continue generating diverse SDI frameworks and indicator sets under weak global coordination.

\(^13\) Pinter, et al. (2005)

The Consultative Group on Sustainable Development Indicators (CGSDI) at IISD as part of their effort to create ‘an internationally accepted sustainable development index’ produced the Dashboard of Sustainability, a performance evaluation tool, in 2001. More recently developed indices include Total Material Requirement by EEA (2001), Eco-efficiency Indices by WBCSD (2003), the Compass of Sustainability by AtKisson (2005), Environmental Sustainability Index (ESI) and Environmental Performance Index (EPI) by YCELP, CIESIN, WEF and EU (2005, 2006).

Most of these indices are not used by policy-makers due to measurement, weighting and indicator selection problems (Bartelmus, 2001). However, some of them are popular among different stakeholders. HDI, Ecological Footprint, ISEW, GPI and EPI have been computed by researchers for a number of countries under different assumptions due to the variation in data quality and availability. The UNDP publishes HDI for all countries in its annual Human Development Report. Environmental Pressure Indicators (EPI), ‘a comprehensive set of indicators for the EU’, published in 1999, 2001 and 2003 showed the trends of 48 indicators that are believed to reflect the most important human pressures on the environment. The Pilot 2006 Environmental Performance Index (EPI), released at the annual meeting of the World Development Forum, is a composite index from a set of 41 indicators that were calculated for 134 countries.

There are two distinct methodologies that can be found in all of these. Mainstream economists use monetary aggregation method, whereas scientists and researchers in other disciplines prefer to use physical indicators. Economic approaches include greening the

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14 Also see Pinter, et al. (2005)
15 See Moffatt (1996) for a partial list of methodologies.
GDP, resource accounting based on their functions, sustainable growth modelling, and defining weak and strong sustainability conditions. For example, recently developed ISEW and GPI are corrections of the National Income (NI) accounts for environmental and some other non-market activities to reflect Hicksian income\(^{16}\). Some of the indicators that are unaccounted for, or not accounted for as costs, in the GDP, but are included in either ISEW or GPI as ‘defensive expenditures’\(^{17}\), are private expenditures on health and education; costs of commuting, urbanization and auto accidents; costs of different types of pollution, depletion of non-renewable resources and long term environmental damage; the value of volunteer work; and the costs of crime, family breakdown, underemployment, etc.

Mainstream economists assume sustainable growth to be a part of sustainable development of the economy.\(^{18}\) In neo-classical models, natural environment is valued for its functions and economic welfare is measured in terms of the level of consumption.\(^{19}\) Therefore, sustainable growth models from this paradigm seek to find a non-declining per capita consumption path over an infinite time horizon through optimal use of resources and technology including discounted benefits from environmental functions and non-renewable natural resources. Substitution possibility between different types of capital is assumed in different forms.

The Hicks/Lindahl requirement for sustainable income is non-declining value of the aggregate capital stock (per capita produced capital, \(k_p\) and per capita natural capital, \(k_n\)) over time. Therefore, Perrings (1996) defines an economy at any level of per capita produced capital (\(k_p\)) to be sustainable, if \(\Delta k_p + \Delta k_n \geq 0\) for all \(t\). Economic development, as he defines it, is sustainable if \(\Delta k_p \geq 0\) and \(\Delta k_p + \Delta k_n \geq 0\). These conditions allow per capita natural capital (\(k_n\)) to decline over some finite time. Perrings' (1996) sustainability condition can be transformed to \(\Delta k_n/\Delta k_p \geq -1\). Therefore, it implicitly assumes less than perfect to a perfect substitutability between produced and natural capital. Weak sustainability condition assumes perfect substitutability between produced and natural capital.

\(^{16}\) Hicks (1946). Hicksian income is an amount of income that people can ‘consume without impoverishing themselves’, which is comparable to maximum sustainable consumption.

\(^{17}\) Daly and Cobb (1989)


capital and strong sustainability condition assumes no substitutability. Pearce, et al. (1989, 1993) compute the critical levels of different natural capital to measure strong sustainability.

The assumption of secular improvement in factor productivity can ensure sustainability in neo-classical growth models. In the Solow-Hartwick framework, sustainable growth path is different from the optimal growth path, which means that sustainability can be achieved at the cost of efficiency. Norgaard (1992), however, contends that efficiency is not the objective in sustainable development. Some recent models from the neo-classical paradigm have explored direct relationship between technological progress and sustainability. Endogenous growth models make the nature of technological progress explicit. The evolutionary modellers use inductive reasoning instead of trying to find the steady state. They are particularly concerned about fostering technical and institutional changes to reach sustainability. The theme of ecological economics model is socio-economic and ecological co-evolution. Neo-Ricardian models of sustainability seek ‘continual maintenance and joint renewal of economic and ecological structures’, for they are assumed to be interdependent joint production processes.

For natural resource accounting, some economists use conventional capital theory that acknowledges the possibility of conversion of natural resource capital to other forms of capital. Repetto, et al. (1987) used the depreciated values of natural resource stocks from the decreased values of the marketed commodities produced by the resource stocks to estimate resource depletion. El Serafy’s (1988) unit rent approach attempts to estimate the portion of income from resource liquidation that needs to be set aside as capital investment “in order to create a perpetual stream of income that would sustain the same level of true income, both during the life of the resource as well as after the resource had been exhausted.”

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20 Solow (1974) and Hartwick (1978)
21 Some economists, including Samuelson, in 1940s and 1950s, showed that it is theoretically impossible to differentiate between efficiency and equity.
22 Christensen (1996)
23 Faucheux, et al. (1996)
24 Peskin (1989); Peskin and Hecht (1992); Brekke (1997)
Mainstream economists prefer monetary valuation simply because it represents the scarcity value of resources. Those who oppose it argue that in absence of a complete demand curve, correct shadow prices cannot be computed. Therefore, economic models must assume certain preference function for capital allocation in the future, which is debatable. Besides, ‘there is no widely accepted model of the transformation processes’ between different types of capital.

Spangenberg (2005) considers ‘the restriction of economic thinking’ to monetary valuation of the functions of different types of capital ‘a serious limitation for the analytical capacity of the discipline’. Citing criticisms, from Ecological Economics (1998), about the assumption of strong substitutability between different types of capital in economic models, Spangenberg (2005) concluded that ‘from a scientific point of view, there cannot be such a thing as one comprehensive measure or index of sustainability’. Scientists prefer policies that use methodologies such as physical accounting of various stocks of natural resources, maximum sustained utilization rate for elements of the environment, or critical loads. Economists, however, find policies based on any such mechanism arbitrary and inefficient, though many international agreements use these mechanisms to ensure, in their words, sustainable use of natural resources and the environment.

Many of the methodologies discussed above can be considered as preliminary ‘iteration(s) in an ongoing process’. As a ‘pragmatic way forward’, Pinter, et al. (2005) recommended for using a ‘maximum of three to five indicators, related to high-priority policy issues’. My attempt in this paper will be to show a direction how different indicators can be integrated into a set of six indices, and how they can be combined to find a sustainability index and a set of sustainability conditions.

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26 UN (1993)
27 See Bojö, et al. (1989); Theys (1989); Alfsen, et al. (1987)
28 This is the utilization rate above which an environmental condition becomes unsustainable.
29 This is ‘the highest deposition load that a receptor can withstand without long-term damage occurring’ (Hall, 1993).
31 1985 Helsinki Protocol agreed to cut emissions of sulphur oxides by an arbitrary sixty percent of what is in excess of the critical load. 1997 Kyoto Protocol asked for a reduction of the emissions of six greenhouse gases by at least five-percent below the 1990 levels in the next fifteen years.
32 Peskin and Hecht (1992)
3. Working Definition of Sustainability

In order to define a sustainability index or a sustainability condition, one must have a working definition of sustainability and a set of sustainability indicators.

The general objective of a human being on earth is to live a long and quality life.\(^{33}\) Therefore, longevity and quality of life should measure human well-being. Besides biological and medical factors, life expectancy and the quality of life are influenced by economic, ecological, and social as well as institutional variables.

The Human Development Index\(^ {34} \) (HDI) of the UNDP can be used as a proxy for social well-being, because they are expected to be highly correlated. In HDI, two-third weight is assigned to quality of life and one-third to longevity. However, it is expected that if the quality-quantity trade-off arises between two groups,\(^ {35} \) quality will give way. An Equity Index should be computed to capture any such disparity. A non-discriminated environment for flourishing human potential is important. The Equity Index should be defined to measure that as well. This is consistent with the concept of sustainable development, because intergenerational equity is a distant objective while intra-generational equity is not achieved.

Although social norms in each nation have to be ethnocentric, some basic human rights need to be secured in any nation. I propose that a Social Condition Index (SOC) be computed, which will reflect social perception rather than just the authority's perception about various issues.

A practical social objective, then, can be to attain HDI = 1 and sustain the achieved level of HDI forever. Any improvement in HDI requires the use of different factors of production. The Damage Index of Natural and Social Environments (DINSE), in my analyses, captures the damages or more precisely, changes to the elements of natural and social environments. We should not exhaust them so that their non-

\(^{33}\) Any philosophical debate on the purpose of life on earth is beyond the scope of this research.

\(^{34}\) HDI is not defined to measure sustainable development (SD). Therefore, it does not meet the required conditions to be the only indicator of SD. HDI cannot distinguish whether a particular level of human development has been attained with an *environmentally sustainable technology* (EST) or not. If a lower HDI were *always* a result of environmental degradation and natural resource depredation, only then it could be a satisfactory measure of SD. However, HDI, as it is presently defined, can be one of the several indicators of SD.

\(^{35}\) For example, an improvement in the quality of life for a group may pose threat to the existence of another group of people. This may be particularly true for many endogenous people in different nations.
availability becomes a constraint for future generations to attain a quality life.\textsuperscript{36} By definition, DINSE = 1 implies either human extinction or a condition that is unsuitable for human habitat. Therefore, sustainability requires that DINSE be in [0, 1) as \( t \to \infty \).

If the present generation could precisely estimate changes to future development potentials due to present economic activities, the rate of growth in factor productivity needed to sustain the present level of consumption or welfare in the future could, then, be predicted from an economic growth or development model.\textsuperscript{37}

Therefore, a working definition of sustainable development should include the following:

(i) Human Development (HD), as defined globally.

(ii) Equity (E), as a society defines it. If there is a trade-off between human development and equity objectives, a society may prefer not to pursue equity objective at the cost of HD or vice versa.

(iii) Damage Index of Natural and Social Environments (DINSE), and

(iv) Future Development Potentials (FDP).

Hence, I define sustainable development as finding the optimal human development (HD), with minimal damage to natural and social environments (DINSE) and future development potentials (FDP), in order to maximize the well-being of the largest number of people in present and future generations.

A set of indicators can be identified from this definition.\textsuperscript{38} While the Bruntland Commission calls for not truncating the ability of future generations to meet their needs, my definition calls for not decreasing future development potentials, which can be measured at present time, \( t = 0 \). I am measuring present progress in terms of \textit{end goals} such as human development (HD) rather than \textit{means} such as consumption. Since

\begin{itemize}
  \item \textsuperscript{36} Whether future generations will be able to maintain the present quality of life or enjoy a much lower or higher quality of life vastly depends on their ability to cope with changing population and technology. However, we do not want them to be constrained by the conditions of NSE.
  \item \textsuperscript{37} Sustainable growth models attempt to achieve that under different assumptions.
  \item \textsuperscript{38} My set of indicators includes economic, social (and institutional), and environmental elements. The UNCSD arranges the sustainability indicators into four categories: social, environmental, economic, and institutional. Similarly, in the business world, for example, Genencor International (2000) identifies environment, society/equity and economics as the key elements of its Sustainability Management System.
\end{itemize}
consumption depends on real income, and it is a major determinant of longevity and quality of life, HD and consumption must be highly positively correlated. 39

4. From Working Definition to A Set of Indicators: Analytical Framework

The analytical framework for evaluating current developmental activities is presented in Figure 4.1. Our actions can have positive or negative effects on the well-beings of all generations. Changes to Natural and Social Environments (NSE) are potential routes of negative welfare effects. Any improvement in the quality of NSE, however, will have positive welfare effects.

39 It can be verified with HD and consumption data, using equivalence scales for consumption expenditures. Though we must caution that countries ranked in terms of HD and income or consumption will not be identical. The Human Development Report (2005) shows the non-linear relationship between the growth rates of GDP and HD with country examples.
not required for sustainability in my framework, which is contrary to the so-called *strong sustainability condition*. I do not assume perfect substitutability between natural and produced capital either, as is assumed by the proponents of *weak sustainability condition*.

The inclusion of social variables is justified by a Norwegian survey,\(^{40}\) which showed that ‘family relationship’ was the most important aspect of people's lives. Hirschman (1967) evaluated many World Bank projects and concluded that conventional cost-benefit analysis is not sufficient for determining the success of a project. Social variables that are often left out of the models may later turn out to be the key factors for the success or failure of a project.

If present developmental activities improve present well-being, that can be measured by achievements in end goals. I use the Human Development Index (HDI) to measure achievements in end goals. Unlike in many other definitions of SD, *intragenerational equity* is considered an objective of sustainable development in my definition. Therefore, I use an Equity Index (E) along with HDI to measure present well-being. Inequality, \((1 - E)\), is defined as deprivation of group achievements. A nation cannot improve E unless it changes the conditions of its disadvantaged people.

Besides direct conservation of resources and environmental clean up, there are many present developmental activities, which have spill over effects on future generations. For example, any produced capital, investment in infrastructure or investment in housing will generate benefits for many future years to come. Therefore, when we consider the cost of present development on future generations in terms of natural resource use or degradation of natural environment we should also consider these positive effects on future well-being from the present use of resources. Similarly, it must be acknowledged that foreign debt accumulated by the present generation is a burden for future generations. Therefore, I compute Capital-Debts Index (CDI) as a partial measure for future development potentials.

Changes in factor productivity and technology are also important determinants of future well-being. They can possibly offset the negative effects of present depletion of resources. Therefore, the current level of productivity or state of technology in a nation\(^{41}\)

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\(^{40}\) Listhaug and Huseby (1990)

\(^{41}\) I do not make any distinction between a nation and a country in this paper.
compared to the potential, called a Productivity Index (P), must be considered for an understanding of the future development potentials.

All of the above factors, which have positive welfare effects, are most likely to change the present state of natural and social environments, and therefore they may have negative welfare effects as well. For sustainability, it may not be necessary to maintain the present state of natural and social environments forever, but natural and social environments have to be above the critical levels till \( t \to \infty \). The sustainability condition must ensure that.

Index of damage to NSE is defined here as:

\[
\text{DINSE} = \max \{ \text{ENV}, \text{NAT}, \text{AMN}, \text{SOC} \},
\]

Where \( \text{ENV} \) = An index for environmental depredation,
\( \text{NAT} \) = An index for natural resource depletion,
\( \text{AMN} \) = An index for the destruction of natural amenities, and
\( \text{SOC} \) = An index for the degradation of social quality.

All indices are in \([0, 1]\).

The justification for using the worst condition of a subsystem of NSE as the damage index is because each subsystem ‘has to have the capability to maintain its capability to survive and evolve’.\(^{42}\) If a nation runs out of a particular natural resource, or degrades its environmental quality or social conditions too much, the people of that nation will have to bear the primary consequence.\(^{43}\) If a natural resource is used for augmenting economic growth or for capital formation, the nation may be able to acquire the exhausted natural resource from other nations, possibly at a higher price (if the exhaustion or depletion of the resource in that nation causes global scarcity).\(^{44}\) However,

\(^{42}\) Spangenberg (2005). Also, see Dewan (1998)

\(^{43}\) The age of colonialism is over. This is a time when disintegration and fragmentation of nations is more common. Foreign assistance may contribute to economic development in some nations. But its role is limited. Globalization has made capital more mobile, and foreign investment may have some positive effects on economic development, sustainable or otherwise. With the collapse of communism, the strategic need for making model nations across the globe has faded. No developing nation in recent history could join the group of developed nations without their own resources – natural, produced, social or human.

\(^{44}\) The Club of Rome (1972) drew a gloomy picture of the future world with the prediction of possible exhaustion of major non-renewable natural resources in the near future. They failed to recognize the price adjustment mechanism with scarcity of resources in their model. Nordhaus (1992), on the other hand, contended that the prices of natural resources had rather been declining, which was inconsistent with an emerging resource scarcity. Present, 2005-06, price hikes of oil and gold are due to demand-supply phenomena, rather than scarcity due to exhaustion of resources.
that may not be possible for depleted environmental conditions, natural amenities or social conditions. They will require what some researchers call ‘defensive expenditures’, causing economic growth to decline. Since the maximum damage done to an area of NSE is used to calculate DINSE, the coefficient of variation, V, of different quality indices should be monitored as well.

Hence, a set of sustainability indicators can be defined as:

$$SDI = \{HDEI; DINSE; CDPI\} = \{HDI, E; DINSE_{\text{max}}, V; CDI, P\}$$

For example, assume that SDI = \{0.7, 0.8; 0.3, 0.2; 0.7, 0.8\} in a nation. It can be interpreted as the nation achieving a moderate level of human development (0.7) with a relatively low inequality (1 - E = 0.2). This progress, however, is not without a cost. Thirty percent damage has been done to a sub-system of natural and social environments. The standard deviation relative to the mean of the damage indices is twenty percent. Produced capital net of the debt burden is 0.7, which implies that the debt-capital ratio is thirty percent. The average productivity in this nation is eighty percent of its potential, which indicates that there is scope for further technological adoption and efficiency-gain.

A production function for HDI, if defined, with DINSE as an input can help determine the optimum HDI growth rate for a given maximum allowable DINSE in a period. Policy-makers must aim for least-DINSE achievement of higher HDI, among other things with cleaner and improved technology. Growth rates of the above indicators can be important measures of progress toward sustainability.

The analytical framework, in this section, gives a direction how to integrate a multitude of indicators into a smaller set of indicators.\(^{45}\) Integration of those into a single composite index is rather challenging. Based on a research project in Nigeria, Morse, \textit{et al.} (2001) concluded that in order to make a decision from a set of sustainability indicators quantitative integration approach is not adequate; the use of a qualitative integration approach incorporating value judgements and subjectivity is ‘inevitable’. In my analyses, values of some of the indicators are subjective, some are based on pure scientific information, and some are based on multi-disciplinary knowledge. However, the final integration approach, as discussed in section 6, is based on economic principles.

\(^{45}\) It can be referred to as “Indicator Pyramid or funnel”. See Braat (1991) and Dewan (1998) for discussion.
5. **A Mathematical Model**

Due to ‘restrictive formalization’ of the environmental component, contemporary models often give ‘imprecise criteria’ of sustainability (Gastaldo and Ragot, 1996). That is one reason why I do not intend to get a closed form solution of the model in this paper. The intention here is to identify the important determinants of sustainability in order to define sustainability conditions, and possibly a sustainability index.

Assume a two-period model, where HDEI is a proxy for human well-being. Therefore, the objective function for a society at \( t = 0 \) is to maximize present and expected future well-being given resources (natural, physical and human); technology; environment (ENV); and socio-cultural, political and institutional conditions (SOC). Since these can be categorized as different types of capital, the sustainability problem can be written as:

\[
\text{Maximize } SD = W \{\text{HDEI}_0, E(\text{HDEI}_F)\},
\]

Where \( W \) = a function of human well-being,

\( 0 = \text{present}, \ F = \text{future}, \ \text{and } E = \text{expected value} \).

Given (i) natural capital \((K_n)\),
(ii) man-made capital \((K_m)\),
(iii) human capital \((K_h)\), and
(iv) social capital \((K_s)\).\(^{46}\)

One of the controversies of economic sustainability is ‘whether each capital stock has to be maintained independently (Daly 1991), or whether the sum of all four capital stocks has to be non-declining (Pearce, Turner 1991)’.\(^{47}\)

**Decomposition of HDEI:**

\[
\text{HDEI}_0 = f_0 \text{ (BLACK BOX)} = g_0 \ (\text{HDEI}_1, \gamma_{n0} K_{n0}, \gamma_{m0} K_{m0}, \gamma_{h0} K_{h0}, \gamma_{s0} K_{s0})
\]

\[
= h_0 \ (\text{HDEI}_1, Z_0) = h_0 \ (H_1, Z_0),
\]

where \( \gamma = \text{usage or extraction rate} \).

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\(^{46}\) "Social capital" usually refers to public investment on infrastructure, education and so on. In my definition, "social capital" or SOC includes those variables that affect socio-cultural, political and institutional conditions in a country. Investment on infrastructure is part of \( K_m \) and public investment on education is part of \( K_h \) in my framework. By definition, \( K_s \) includes social variables such as family relationship, cultural norms, and so on.

\(^{47}\) Spangenberg (2005)
$Z = \text{all } \gamma K\text{'s and } H = \text{HDEI}$

$\text{HDEI}_F = f_f (\text{BLACK BOX}) = g_f (\text{HDEI}_0, \gamma_{nF}K_{nF}, \gamma_{mF}K_{mF}, \gamma_{hF}K_{hF}, \gamma_{sF}K_{sF})$

$= h_f (\text{HDEI}_0, Z_F) = h_f (H_0, Z_F)$

**The Model:**

The sustainability objective is to:

Maximize $W \{HDEI_0, E (HDEI_F)\}$

$\Rightarrow W [h_0 (H_1, Z_0), E \{h_f (H_0, Z_F)\}]$........................ (5.A1)

Where $h_0 (Z_0), h_f (Z_F) \geq 0$

and $\left( \frac{\partial Z_F}{\partial Z_0} \right) \leq 0$, for $K_F = f (\gamma K_0)$, where $f \leq 0$

$\Rightarrow W [h_0 (H_1, Z_0), E \{h_f \{h_0 (H_1, Z_0), Z_F\}\}]$

$\Rightarrow W [h_0 (H_1, Z_0), E \{k_f (H_1, Z_0, Z_F)\}]$

Where $k_f (H_1, Z_0, Z_F) = h_f \{h_0 (H_1, Z_0), Z_F\}$

$\Rightarrow W [(H_1, Z_0, E (Z_F))]$........................................ (5.A2)

where $H_1 = \text{previous period's } H \text{ and fixed at } t = 0$

$\Rightarrow W \{H_1; \gamma_{n0}K_{n0}, \gamma_{m0}K_{m0}, \gamma_{h0}K_{h0}, \gamma_{s0}K_{s0}; E (\gamma_{nF}K_{nF}, \gamma_{mF}K_{mF}, \gamma_{hF}K_{hF}, \gamma_{sF}K_{sF})\}$

The present capital stock, $K_0 = K_{-1} + \Delta K_{-1} + \Delta K_0$

Similarly, the future capital stock, $K_F = K_0 + \Delta K_0 + \Delta K_F$

where $\Delta K_i = \gamma_i K_i + \varphi_i K_i, \forall i = 0, F$

$\gamma = \text{rate of extraction/ usage } [\gamma \leq 0]$

$\varphi = \text{rate of innovation } [\varphi \geq 0]$

$\Rightarrow W [H_1; \Phi_{n0}K_{n0}, \Phi_{m0}K_{m0}, \Phi_{h0}K_{h0}, \Phi_{s0}K_{s0}; E \{\gamma_f (\Delta K_{nF}, \Delta K_{mF}, \Delta K_{hF}, \Delta K_{sF})\}]$

Where $\Phi_j = m \{\gamma_{j0}, E (\gamma_{jF})\}, i \in \{0, F\} \text{ and } j \in \{n, m, h, s\}$

$\Rightarrow W [H_1; K_0, \gamma_0, \varphi_0, E (\gamma_{fF}), E (\varphi_F)]$

This model assumes that the discount rate$^{48} \delta$ and the population growth rate $n$ both are zero. For a positive population growth rate, per capita measures are more appropriate for some forms of capital except environmental and social capitals. At $t = 0$,

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$^{48}$ The discount rate controversy has been discussed in section 6.4.
the present generation can affect $W$ through $\Delta K_0$'s, by affecting $H_0$ and $H_F$. $\Delta H_0$ can be directly measured, but at $t = 0$, $\Delta K_F$'s are uncertain. This uncertainty is the source of all controversies about conservation of resources.

If $[K_0 - \sum_{F=0}^{\infty} \Delta K_F] \geq K_{\text{critical}}$, the problem of unsustainability does not exist at least from an economist's perspective. From past experience, some extrapolate that new innovations, technological advancement, and new substitution possibilities between alternative resources will compensate for any current use of resources. However, some argue for resource-conservation on the ground of Entropy Law.

Due to environmental regulations, conservation, etc. if less $Z_0$ is available for present usage, i.e., $Z_0^{\text{constrained}} < Z_0^{\text{unconstrained}}$, present human development ($H_0$) will be adversely affected.

If $Z_0^{\text{constrained}} < Z_0^{\text{unconstrained}}$ and $Z_F = h_F(Z_0)$, where $h_F' \leq 0$, the objective function in (5.A1) can be re-written as

Maximize $W [h_0 (H_1, Z_0^c), E [h_F \{H_0^c, h_F(Z_0^c)\}]]$

Where $H_0^c$ = the level of present $H$ attained with constrained resource-use and $Z_0^c$ = the amount of constrained resource-use.

Therefore, from (5.A2) we have the objective function as

Maximize $W [H_1, Z_0^c, E \{h_F(Z_0^c)\}]$

Where $h_F(Z_0^c) > h_F(Z_0^{\text{un}}}..................(5.3)$

In (5.3), $Z_0^{\text{un}}$ stands for $Z_0^{\text{unconstrained}}$. The implication of (5.3) is that $h_F(\Delta Z_0)$ is non-positive, if $\Delta Z_0 \geq 0$. This is because some elements in set $Z$ may not be abundant, or may not be substitutable.

If present usage does not cause resource scarcity in the future, or if enough substitutes are invented to make up for the present use of resources, current usage will not affect future $H$. In that event, present conservation is a waste. However, it can be considered as risk-premium for the future.

To define a sustainability index, no a priori econometric relationship between $H$ and $Z$ needs to be assumed. The above mathematical model, however, establishes that the following variables need to be monitored for sustainability, at $t = 0$:

$\{\Delta H_0, \Delta K_{m0}, \Delta K_{h0}, \Delta K_{s0}\}..................(5.4)$
Therefore, the present generation needs to compute $\Delta H_0$ and $\Delta K_0$, which is an improvement in $H$ and the net usage$^{49}$ of $K$, to measure progress toward sustainable development. In order to assess the level of sustainable development, the stocks of $H_0$ and $K_0$'s must be calculated. For policy purposes, precise functional forms of $h_0(.)$ and $E \{h_F(.)\}$ must be established from further econometric analyses. However, the signs of $h_0(.)$ and $E \{h_F(.)\}$ are predictable.

Based on the above model, for practical convenience I arrange the concerned variables into following three categories:

(i) $\Delta$HDEI = $\Delta H_0$,

(ii) $\Delta$DINSE = $f(\Delta K_{n0}, \Delta K_{s0})$, and

(iii) $\Delta$CDPI = $f(\Delta K_{n0}, \Delta K_{m0}, \Delta K_{h0})$.

The closed economy model, discussed above, can be extended for an open economy by including exports into $\gamma$ and imports into $\phi$. $\gamma$ and $\phi$ must also be re-defined to include foreign aid, foreign debts, etc.

A distinction between economic development and sustainable development can be pointed out here. The objective in economic development is to maximize $\{h_0(H_1, Z_0)\}$, which ignores the cost of development. Sustainable development, however, includes the cost of development in the present welfare function. Therefore, SD must maximize $[h_0(H_1, Z_0^c), E \{h_F \{H_0^c, h_F(Z_0^c)\}]$. In my framework, DINSE measures the cost of economic development.

6. The Sustainability Index and the Sustainability Conditions

Based on my working definition$^{50}$ and the discussions in sections 4 and 5, the core sustainability condition (SC) can now be defined. Let us analyze the following two cases:

**Case I**

Assume that $\Delta D \geq 0$, which means deterioration or a constant level of the quality of NSE. If the NSE deteriorates due to developmental activities the resulting increase in

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$^{49}$ Net Usage = (Usage – Additions through innovations and discoveries).

$^{50}$ If the working definition differs we shall need to change the numerator in the sustainability index accordingly.
human development has to be such that the ratio of \( \Delta H \) to \( \Delta D \) is greater than or at least equal to a minimum threshold value. That value is equal to the ratio of the shortfall of \( H \) from targeted \( H \) and the existing quality of NSE,\(^{51}\) if the agent is risk-neutral and no discounting is assumed. Therefore, the core sustainability condition can be defined as the ratio of marginal \( H \) to marginal \( D \) greater than or equal to the ratio of the gap between targeted and actual \( H \), and the quality of NSE. Perceived risk parameter and discount factor can also be added to the condition. Hence, the basic sustainability condition is

\[
\left( \frac{\Delta H}{\Delta D} \right) \geq \frac{1}{1 + \delta} \left( \frac{1 - H}{1 - D} \right)^{\frac{\gamma}{1 - \gamma}} \hspace{1cm} \text{(6.A1)}
\]

Where \( H = \text{HDI} = \) the Human Development Index, 
\( D = \text{DINSE} = \) the level of damage to NSE,
\( \Delta = \) positive or negative change,
\( \delta = \) the discount factor,\(^{52}\) and
\( \gamma = \) the risk-aversion parameter.\(^{53}\)

\( H, \delta \) and \( \gamma \) are in \([0, 1]\); and \( D \) is in \([0, 1)\).

Re-arranging the terms, the sustainability condition can be written as

\[
\frac{\Delta H}{\Delta D} \geq \frac{1}{1 + \delta} \left( \frac{1 - H}{1 - D} \right)^{\frac{\gamma}{1 - \gamma}} \hspace{1cm} \text{(6.A2)}
\]

Or

\[
\left( 1 + \delta \right)^{\frac{\Delta H}{\Delta D}} \left( \frac{1 - H}{1 - D} \right)^{\frac{\gamma}{1 - \gamma}} \geq 1 \hspace{1cm} \text{(6.A3)}
\]

It’s a condition that compares gains vs. losses. As long as the net gain from an activity is non-negative for all generations, the activity is considered sustainable. The

---

\(^{51}\) It is justified later in this section.

\(^{52}\) An improvement in the present Human Development Index \( H \) may have some positive effect on the future \( H \). This spill over benefit is captured by the non-negative fraction \( \delta \).

\(^{53}\) The sustainability condition requires that the ratio of a change in \( H \) to a change in \( D \) be not less than \( \left( \frac{\gamma}{1 - \gamma} \right) \) order of the ratio of shortfall of \( H \) to the quality of NSE. The value of \( \gamma \) determines the "degree of bias" toward further human development or conservation of resources. Bias toward conservation means taking less risk about the future. Therefore, \( \gamma \) can be interpreted as the "risk-aversion" parameter. The significance of \( \gamma \), the risk-aversion parameter, can be more apparent from the discussions on sustainability conditions and risk premiums in this section and in section 6.4.
The main distinction between the sustainability condition (SC) and the feasibility condition (FC) of cost-benefit analysis is that I do not use monetary valuation method in defining SC, though where possible that should be the preferred option. The numerical value of the left-hand side of the equation (6.A2) or (6.A3) can be called the *Sustainability Index* (SI). The SI can be used to assess and compare country performance toward sustainability or to compare the performance of competing projects.

**Case II**

Assume that $\Delta D < 0$, which means an improvement in the quality of NSE. Since this activity increases expected present and future well-being, some loss in $H$ can be acceptable. Therefore, the basic sustainability condition can be defined as

$$\left( \frac{\Delta H}{\Delta D} \right) \leq \frac{1}{1 + \delta} \left( \frac{1 - H}{1 - D} \right)^{\frac{\gamma}{1-\gamma}} \quad \text{.................. (6.A4)}$$

Re-arranging the terms, the sustainability condition can be written as

$$\frac{\Delta H}{\Delta D} \left( \frac{1 - H}{1 - D} \right)^{\frac{\gamma}{1-\gamma}} \leq 1 \quad \text{................................. (6.A5)}$$

Or

$$\left(1 + \delta\right) \left( \frac{\Delta H}{\Delta D} \right)^{\frac{\gamma}{1-\gamma}} \left( \frac{1 - D}{1 - H} \right)^{\frac{\gamma}{1-\gamma}} \leq 1 \quad \text{................................. (6.A6)}$$

The sustainability condition rules out the possibility of ENV, NAT, AMN and SOC, that is $K_n$ and $K_a$, to ever fall below the *critical levels* until $H = 1$. However, targeted $H$ can be continuously revised upward. The implication of that is the guarantee of a liveable environment for human race. However, that may not be a sufficient condition for sustainability.

Several questions need to be answered in this regard:

(i) What is $H = 1$, and how far in the future could a nation possibly be able to attain that?

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54 Methodologies for defining the critical levels are discussed in Dewan (1998).
(ii) How can we make the time path to reach $H = 1$ infinity, or how can we ensure that $H \to 1$ as $t \to \infty$?

(iii) Isn't it unreasonable not to reach $H = 1$ for the sake of sustainability, even though a nation has the ability to reach that goal at the present time? Why should a sustainability condition even require that? What happens if a nation reaches to $H = 1$ or $D = 1$ at the present time?

(iv) What role does the risk-aversion parameter $\gamma$ or the discount factor $\delta$ play in the development process?

$H = 1$ means that the human race has reached its set goal on earth. We can reasonably believe that as human beings succeed in achieving more and more end goals, they will revise their targets upward. People's craving for higher longevity and a better quality of life will probably never stop even if today's set targets are reached. Therefore, the target value for $H$ will change with changes in technology.

Variable target value for $H$ may be seen as a problem as well. Because given certain $H$ and the present generation's perception about that relative to its desired level of $H$ determines what $\Delta D$ is acceptable at the present time. If the target value for $H$ becomes variable, the present level of acceptable damage may not be the correct choice from the perspective of future generations. An arbitrary target value for $H$ will make the choice of $D$ arbitrary.

In response to this concern, it can be said that sustainability does not require that we ensure a higher quality of life for the future by sacrificing our achievement of a certain quality of life. As long as the present generation acts to ensure the same quality of life for the future, its envisaged goal for the present and the activities should be considered consistent with sustainable development activities. At a future time, many of our available technologies may be proven to be environmentally unfriendly, but we cannot stop using all of them at the present time. Any damage done to the NSE that meets the sustainability condition assuming the present generation's collective judgment about the targeted $H$ is acceptable as sustainable development. The target $H$ set by the UNDP has got some level of acceptance, so it can be used for that purpose.

In the proposed index, we can make the time path to reach $H = 1$ infinity by continuously revising the targeted $H$ upward, as suggested earlier. An alternative is to
define another condition, which could be one of the *sufficient conditions* for sustainability:

\[ \sum_{t=0}^{T} (\Delta D) \leq (1 - D) \] ................................. (6.A7)\(^{55}\)

The issue then is how to make this sufficient condition operational. It can be done by using forecasting models. Risk-perception will play an important role in this decision mechanism. Assuming a large value of T based on the risk-perception of the present generation, maximum allowable D in a period can be computed. It has to be adjusted periodically depending on changing technology and the availability of new information.

In my index, the risk-perception parameter \( \gamma \) is a policy instrument, which is partly determined by the current level of progress and quality of NSE in a nation. If a nation is presently in the *Sustainable Development Region*\(^{56} \), that is \( H > D, \gamma < 0.5 \) indicates that the nation is risk-averse. Assuming smaller and smaller values for \( \gamma \) policy makers in such a nation may pursue more and more risk-averse policies. If a nation is presently in the *Unsustainable Development Region*\(^{57} \), \( \gamma > 0.5 \) indicates risk-aversion. One note of caution is that too high or too low \( \gamma \) can cause a high level of inefficiency.

The sustainability index is simply a quantitative tool that can guide national policy makers. It does not imply in any way that a nation should not achieve \( H = 1 \) at the present time if it can. The index, however, suggests that if \( H = 1 \) is reached; any level of damage is acceptable for a small improvement in \( H \). This is simply because human beings have already achieved their goals on earth.

However, if targeted \( H \) is attained at any present time, the policy makers should re-define their priorities. Instead of further improving \( H \), the priority should be to improve the quality of living conditions, NSE. For these are sources of negative welfare effects. This is consistent with the thought that as people attain most of their end goals in life, they prefer a better environment as well. Also, it is a time when a nation should care

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\(^{55}\) If continuous change is assumed, this condition can be written as

\[ \int_{T=0}^{\infty} dD \leq (1 - D) \Rightarrow \int_{T=0}^{\infty} \frac{dD}{(1 - D)} \leq 1 \Rightarrow - \int_{T=0}^{\infty} \log(1 - D) \leq 1. \]

\(^{56}\) It is defined later in this section.

\(^{57}\) It is defined later in this section.
more about its future generations. Therefore, if \( H \geq 1 \), a nation should use only the second sustainability condition, as specified in (6.A4).

Hence, I suggest using the following sustainability conditions depending on the state of development in a nation:

**Table 6.1: The Sustainability Conditions**

<table>
<thead>
<tr>
<th>If</th>
<th>Then, ( \forall \Delta D \geq 0 )</th>
<th>Then, ( \forall \Delta D &lt; 0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H &lt; 1 )</td>
<td>SI ( \geq 1 )</td>
<td>SI ( \leq 1 )</td>
</tr>
<tr>
<td>( H \geq 1 )</td>
<td>Theoretically, SI ( \geq 1 )</td>
<td>SI ( \leq 1 )</td>
</tr>
<tr>
<td></td>
<td>Practically, not applicable</td>
<td></td>
</tr>
</tbody>
</table>

It should be noted here that any discovery of new resources may cause the level of \( D \) to decline and make the current state of development more sustainable.

The above discussion indicates that the necessary condition for sustainability will ensure that \( K_n \) or \( K_s \) will not constrain the future development unreasonably. However, there may be constraints due to the lack of other forms of capital, namely \( K_m \) and \( K_h \). Therefore, if another condition, \( \Delta k_m, \Delta k_h \geq 0 \), where \( k = \) per capita capital, is added to the previous conditions that would ensure that present progress is attainable in the next period. The availability of \( K_m \) and \( K_h \) partly depends on the availability of \( K_n \). This supports Moffatt's contention that "... Ultimately all economic activities ... are based upon the use of the earth's resource base" (Moffatt, 1996). 58

58 In the Nineteenth Century, Karl Marx talked about two basic factors of production: Man and Nature.
Atkinson 1993; Pearce, Barbier 2000). The question, however, is whether it is feasible to maintain previous levels of capital as $t \rightarrow \infty$.

The necessary condition for sustainability guarantees that $K_a$ & $K_s$ can be kept above their critical levels as long as some resources are available for the bare survival of the present generation. If resources become too scarce, meeting the sustainability condition may imply a fall in $H$. A fall in $H$, however, can be consistent with SD if that meets the sustainability condition. A good feature of the proposed sustainability condition is that not only an improvement in $H$, environmental clean-up or defensive spending can increase the absolute numerical value of $SI$ as well.

I believe that $\Delta CDI$, $\Delta P \geq 0$ can be a substitute for the condition, $k_m$, $k_h \geq 0$. The negative effects of population growth rate should, to some extent, be captured by CDI. CDI can also be re-defined in per capita term to capture the effects of population growth. Since intra-generational equity is an objective of sustainable development in my definition, $\Delta E \geq 0$ should also be added as a sustainability condition. Given the definition of DINSE, it may be better to add $\Delta V \geq 0 \ \forall \Delta D \geq 0$ and $\Delta V < 0 \ \forall \Delta D < 0$ as well.

Therefore, my proposed sustainability conditions are:

1. $SI \geq 1 \ \forall \Delta D \geq 0$ and $SI \leq 1 \ \forall \Delta D < 0$

2. $\sum_{t=0}^{T \rightarrow \infty} (\Delta D) \leq (1 - D)$

3. $\Delta CDI$, $\Delta P$, $\Delta E \geq 0$ and

4. $\Delta V \geq 0 \ \forall \Delta D \geq 0$ and $\Delta V < 0 \ \forall \Delta D < 0$

From now on, throughout this paper I shall use only $SI \geq 1$ to refer to both $SI \geq 1 \ \forall \Delta D \geq 0$ and $SI \leq 1 \ \forall \Delta D < 0$

Meeting the above conditions is sufficient for sustainable development, because it implies that the present generation is not truncating future development potential. However, it does not guarantee that the present level of $H$ will be attainable in all future years. I do not believe that such a condition should be imposed on the present generation. For if natural resources become unavailability at a distant future due to Entropy Law, we cannot just escape that even if we use the resources most sensibly. Sustainability

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59 Spangenberg (2005)
60 The detail interpretations of different sustainability conditions can be found in Dewan (1998).
conditions, however, can guide policy makers in the right direction. Policy makers can set their priorities on whether to further improve H, decrease D or emphasize more on technological improvement based on information provided by the sustainable development indicators.

The Hicks/Lindahl requirement for sustainable income implicitly assumes perfect to less than perfect substitutability between produced and natural capital, and it does not guarantee that a nation will not run out of $K_n$ in the future. In contrast, my proposed index, SI, not only ensures that $\Delta k_p \geq 0$, it also makes certain that the nation will not run out of the quality of NSE as $t \to \infty$. NSE not only includes natural resources, it includes ENV, AMN and SOC as well. Therefore, NSE covers a much broader spectrum.

If $K_n$ becomes scarce in a nation, the sustainability condition requires no further improvement in H. Sustainable development, then, means conservation of NSE. As a result, if H starts sliding down, the numerical value of $\frac{1}{1+\delta \left(1-H \right)}$ will keep falling. Therefore, after a certain point, improving H will again be considered SD.

It may be argued that the sustainability conditions require the poor nations to conserve more given the same state of NSE in rich and in poor nations. This is because a poor nation has less capability. It has to travel a long path to reach the targeted H. Therefore, an environmentally unfriendly technology in such a nation may exhaust its environment before the nation ever reaches $H = 1$.

The proposed SDI and SI are not defined to give a full account of the wealth of a nation. I intend to identify only those variables that change due to our present activities and that have an impact on future generations' well-being. Therefore, meeting the sustainability conditions does not guarantee that a poor nation will succeed in making progress. However, SI is an indicator that shows whether a nation is on the right path of development. Equivalent value for the SI in two nations does not mean that both nations are the same in terms of social well-being. To understand the actual level of social well-being we need to compare HDEI from the set of SDI.

61 The Kyoto Climate Change Convention in December 1997 called for using environmentally sound technology (EST) in all nations. However, the method of transferring EST from developed to developing nations is still a debatable issue.
Serageldin (1993) advocates growth, equity, and efficiency as well as social and ecological sustainability. Meeting the *sustainability conditions*, presented in this section, ensures that $\text{NSE} \neq 0$ as $t \to \infty$. NSE includes both social and ecological variables. One of the sustainability conditions, $\Delta E \geq 0$, ensures that inequality is not increasing with development. Instead of using per capita GDP growth to measure progress, I use the change in human development index (H), where per capita GDP is one of the components. Therefore, my proposed sustainability index seeks economic and social as well as ecological sustainability.

By definition, the SI shows the cost of growth of H in terms of the percentage damage to NSE. To give an example, assume that $\text{SI} = 4$ in a risk-neutral nation. It means that the nation's progress in closing the gap between targeted and actual H is four times the damage done to the quality of NSE, when measured on a one-point scale. In other words, with one percent damage to the quality of NSE, the nation has closed four percent of the gap between targeted and actual H.

**The Sustainability Index, and the Damage and the NSE Elasticity of H**

(1) The Damage Elasticity of H, $E_{dh} = \left( \frac{\Delta H}{H} \right)$

We know that

\[
\text{SI} = \left( \frac{\Delta H}{\Delta D} \right) \left( \frac{1 - D}{1 - H} \right) , \text{ when } \delta = 0 \text{ and } \gamma = 0.5
\]

\[
\Rightarrow \text{SI} = \left( \frac{\Delta H}{\Delta D} \right) \left( \frac{D}{H} \right) \left( \frac{1 - D}{1 - H} \right) \left( \frac{H}{D} \right)
\]

\[
\Rightarrow \text{SI} = E_{dh} \times \left( \frac{1 - D}{1 - H} \right) \left( \frac{H}{D} \right)
\]

If a nation is presently in the sustainable development region, then $\text{SI} > E_{dh}$. On the critical path of SD,\(^{62}\) where $H = D$, $\text{SI} = E_{dh}$.

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\(^{62}\) The Critical Path is defined in section 6.3.
(2) The NSE Elasticity of \( H \), \( E_{nseh} = \left( \frac{\Delta H}{H} \right) \frac{1 - D}{(1 - D)} \), since \( \Delta(1-D) = - \Delta D \)

\[ E_{nseh} = - \left( \frac{\Delta H}{\Delta D} \right) \left( \frac{1 - D}{H} \right) \]

\[ E_{nseh} = - \left( \frac{\Delta H}{\Delta D} \right) \left( \frac{1 - D}{1 - H} \right) \left( \frac{1 - H}{H} \right) \]

\[ E_{nseh} = - SI \left( \frac{1 - H}{H} \right) \], assuming \( \delta = 0 \) and \( \gamma = 0.5 \)

\[ SI = - E_{nseh} \times \left( \frac{H}{1 - H} \right) \]

If the Human Development Index (H) is less than 0.5, the absolute value of the Sustainability Index (SI) is greater than \( E_{nseh} \). For \( H = 0.5 \), \( SI = - E_{nseh} \).

### 6.1 Strong and Weak Sustainability Conditions

Given the sustainability conditions in previous section, here I shall define various degrees of sustainability. For all sustainability conditions may not be met at any present time in a nation. Among the stated conditions, \( \sum_{t=0}^{T} \Delta D \leq (1 - D) \) cannot be computed precisely at \( t = 0 \). To get a base-line figure, an allowable \( \Delta D \) can be calculated as \( \Delta D \leq (1-D)/T \)\(^{63}\) by assuming a very large \( T \). It should be revised periodically based on new information.

Various degrees of sustainability are defined in Table 6.2:

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\(^{63}\) Compare with the indices from The Limits to Growth.
Table 6.2: Various Degrees of Sustainability

<table>
<thead>
<tr>
<th>Degree of Sustainability</th>
<th>Conditions</th>
</tr>
</thead>
</table>
| Perfectly Sustainable    | (a) SI ≥ 1; ΔE, ΔCDI, ΔP, ΔV ≥ 0 ∀ΔD ≥ 0  
(b) SI ≤ 1; ΔE, ΔCDI, ΔP ≥ 0; ΔV < 0 ∀ΔD < 0 |
| Strongly Sustainable     | (a) SI ≥ 1; ΔCDI ≥ 0 ∀ΔD ≥ 0  
(b) SI ≤ 1; ΔCDI ≥ 0 ∀ΔD < 0 |
| Weakly Sustainable[^64]  | (a) SI + ΔCDI/ΔD ≥ 1 ∀ΔD ≥ 0  
(b) SI + ΔCDI/ΔD ≤ 1 ∀ΔD < 0 |
| Unsustainable            | (a) SI + ΔCDI/ΔD < 1 ∀ΔD ≥ 0  
(b) SI + ΔCDI/ΔD > 1 ∀ΔD < 0 |
| Non-Development          | (a) SI < 1; ΔCDI < 0 ∀ΔD ≥ 0  
(b) SI > 1; ΔCDI < 0 ∀ΔD < 0 |

[^64]: Sustainability conditions allow meeting present needs at the cost of natural and social environments. Perfect substitutability between natural and man-made capital can be assumed for weak sustainability. See "Nine States of Economic Development" in Dewan (1998).

6.2 Sustainable Development Region and the Critical Path

Sustainability conditions guarantee the attainment of targeted H without completely destroying the quality of NSE. Consider Figure 6.1.
In Figure 6.1, at point A, $H > D$, at point B, $H = D$ and at point C, $H < D$.

If the damage elasticity of $H$, $E_{dh} = 1$, the nation at point C will never reach $H = 1$. It will exhaust all of the quality of NSE before reaching all end goals. Therefore, the nation should emphasize more environmentally friendly and less natural resource consuming technologies on its development planning. This is true for any point inside the triangle ONP. I call this *Unsustainable Development Region*, for this is probably indicative of past careless destruction of the quality of NSE for economic development.

The nation at point A can always reach $H = 1$ without exhausting the quality of NSE, if $E_{dh} = 1$. This is true for any point in the triangle OPM. I call this *Sustainable Development Region*. Even to some extent relatively environmentally unfriendly technology will not cause an immediate catastrophe in such a nation. For a nation in the SD region it’s implicit that in the past $E_{dh}$ was greater than one on its development path for sometime. Therefore, as long as $\left(\frac{H}{D}\right) > 1$, it may be feasible for a nation to maintain the present level of $H$ without much deteriorating the quality of NSE, for it did that in the past.

For the nation at point B, $H = D$. As long as $E_{dh} > 1$, it could reach $H = 1$ before reaching $D = 1$. However, if $E_{dh} = 1$, it will exhaust the quality of NSE to reach $H = 1$. It applies to any point on OP; therefore, this is the *Critical Path for SD*. Use of environmentally friendly technology should be the priority in such a nation.
National policy makers should formulate their development strategies in a way so that the nation does not fall in the unsustainable development (USD) region at any time. Their objective should be to reach a point on MP, in Figure 6.1, without increasing much of D. Thus a nation in the USD region must pursue a risk-averse policy.

### 6.3 Simulations

Using continuous, instead of discrete, changes to H and D, the sustainability condition can be defined in terms of a differential equation as follows:

\[
\frac{dH}{dD} \geq \frac{1}{1 + \delta} \left(\frac{1 - H}{1 - D}\right)^{\frac{\gamma}{1 - \gamma}}, \text{ Where } H, \delta \text{ and } \gamma \text{ are in } [0, 1]; \text{ and } D \text{ is in } [0, 1].
\]

\[
\Rightarrow \int \frac{dH}{(1 - H)^{\frac{\gamma}{1 - \gamma}}} \geq \frac{1}{1 + \delta} \int \frac{dD}{(1 - D)^{\frac{\gamma}{1 - \gamma}}}
\]

\[
\Rightarrow \zeta (1-H) \leq (1-D), \text{ Where } \zeta \text{ is a constant in terms of } \gamma \text{ and } \delta.
\]

This is intuitive that, over time, sustainable development path should be in the Sustainable Development Region. Using the marginal condition, or equality, we can solve this equation for different values of the choice variables, and plot those to find sustainable development trajectories.

#### Sustainable Development Trajectories

Consider a numerical example. Assume that H = 0.6 and D = 0.3 at point A in Figure 6.2. Therefore, \( \frac{H}{D} = 2 \), (1-H) = 0.4 and (1-D) = 0.7.

(A) If \( E_{dh} = 1 \) \( \Rightarrow \frac{\Delta H}{\Delta D} \left(\frac{D}{H}\right) = 1 \)

\[
\Rightarrow \left(\frac{\Delta H}{\Delta D}\right) = \left(\frac{H}{D}\right) = 2
\]

Therefore, the nation will reach at point K in Figure 6.2, where H = 1 and D = 0.5.

---

65 This section will be completed as soon as I am able to work out exact and numerical solutions of the sustainability condition, specified by a differential equation, for a certain increment of D and different values of \( \delta \) and \( \gamma \); and am able to plot them on a graph by using Matlab.
(B) If \( E_{dh} = \frac{1}{2} \)  \[ \Rightarrow \left( \frac{\Delta H}{\Delta D} \right) \left( \frac{D}{H} \right) = \frac{1}{2} \]

\[ \Rightarrow \left( \frac{\Delta H}{\Delta D} \right) = \frac{1}{2} \left( \frac{H}{D} \right) = 1 \]

Therefore, the nation will reach at point E in Figure 6.2, where \( H = 1 \) and \( D = 0.7 \). The social well-being at point K is always greater than the social well-being at point E.

(C) We know that the basic sustainability condition is: \( SI \geq 1 \)

\[ \Rightarrow (1 + \delta) \left( \frac{\Delta H}{\Delta D} \right) \left( \frac{1 - D}{1 - H} \right)^{\gamma} \geq 1 \]

Now, let’s consider the following cases.

**Case I**

Assume that \( \delta = 0 \) and \( \gamma = 0.5 \), which means no discounting and risk-neutrality.

Meeting the sustainability condition at point A means that \( \left( \frac{\Delta H}{\Delta D} \right) \geq \frac{0.4}{0.7} \). Hence, through the *Marginal Sustainable Development Path*, a nation at point A will reach at point P in Figure 6.2, where \( H = 1 \) and \( D = 1 \).

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66 *Marginal SD Path* refers to the path of economic development when meeting the sustainability condition marginally.
Case II

Assume that $\delta = 0$ and $\gamma = 0.25$, which means no discounting, but some risk-aversion.

Therefore, \[
\left( \frac{\Delta H}{\Delta D} \right) \geq \left( \frac{0.4}{0.7} \right)^{0.25} \left( \frac{1}{1-0.25} \right)
\]

$\Rightarrow \left( \frac{\Delta H}{\Delta D} \right) \geq 0.83$

In this case, by meeting the sustainability condition marginally the nation can reach at point F in Figure 6.2, where $H = 1$ and $D = 0.78$. Therefore, for this nation, $\gamma = 0.25$ implies 22 percent less damage to NSE to attain targeted $H$. However, a smaller $\gamma$ may increase the total travel time to reach $H = 1$.

Case III

Assume that $\delta = 0$ and $\gamma = 0$, then $SI \geq 1 \Rightarrow \left( \frac{\Delta H}{\Delta D} \right) \geq 1$.

Hence, the marginal SD path will lead the nation to point E in Figure 6.2, where $H = 1$ and $D = 0.7$. Given the risk perception of this social planner, point F is, therefore, not sustainable.

When a nation is in the SD region, any $\gamma < 0.5$ indicates that the nation is pursuing a conservative economic development policy. It may cause some efficiency loss, however it ensures that the people in that nation will attain the end goals without destroying all of its NSE.

For a nation at point C in Figure 6.3, $E_{dh}$ on the development path has to be greater than one for sustainability. Meeting the sustainability condition marginally would ensure that the nation would not reach any point on NP. Depending on the value of $\gamma$ we can get different sustainable development trajectories as showed in Figure 6.3.
Figure 6.3: Sustainable Development Trajectories

If a nation reaches at any point on MP in Figure 6.3, future development objective should be shifted to increase the quality of NSE, because any point toward M on the line MP is preferable to any point closer to P from the social point of view.

6.4 Discounting, Risk and Uncertainty Premiums, Deadweight Loss

Discount Rate

Discounting future generations’ benefits and costs is a key feature of economic models, and is often challenged by some as inconsistent with sustainability. Following Faustmann (1849) and Hotelling (1931), interest rate has been used as the discounting factor in models of natural resource management. Mäler (1992) opposes the concept of using the market rate of interest in discounting future welfare since it does not reflect the present and future productivity of ecological systems. Friend (1992) suggests adding an ethical component to interest rate to reflect intergenerational equity. Some economists suggest using a lower discount rate to tackle the problem. However, a lower social rate of discounting can make investment less expensive, and therefore increase the exploitation of the natural environment. In the sustainability literature, one can find arguments against using time preference as a discount factor. Since ΔH and ΔD in my index are not monetary measures, it makes little sense to use only interest rate as the discount rate (δ). If any discounting is used that should be based on interest rate and projection of spill over benefits expected to be received by future generations from present development.
**Uncertainty**

"The expected value of benefits under uncertainty is less than the value of benefits under certainty… Therefore, we should err on the side of under investment, rather than over investment, *since development is irreversible*" (Arrow & Fisher, 1974). My sustainability index is defined in alignment with this philosophy. That is why I use maximum damage to a sub-system of NSE as the damage index (D). It has the potential of causing efficiency loss, but that can be minimized through periodic stocktaking of achievements and costs to NSE.

**Risk Perception**

Any development planning that includes future generations in the planning horizon must assume some form of risk-perception. The risk parameter can be computed *objectively* from the level of development and the *stocks* and the *critical levels* of resources, environmental quality and social conditions.

(i) **Risk-averse nation:** A risk-averse nation preserves more than necessary resources for the future. It may cause the present well-being to decline. Whether the future well-being will increase or the present natural resource conservation policy will simply be considered *inefficient* will depend on how future generations succeed in innovating, discovering and/or substituting these resources. Therefore, the present generation in a risk-averse nation pays a relatively high risk-premium for the security of future generations. $\gamma$ in the sustainability index is relatively low for such a nation, when $D < H$ and relatively high, when $D > H$.

(ii) **Risk-neutral nation:** To the social planner of a risk-neutral nation 

\[ V \{W_0(\hat{R})\} = V [E \{W_F(\hat{R})\}] \]

*Where $V =$ weight,*

\[ E = \text{expected value},\]

\[ W_F = \text{welfare function at a future time},\]

\[ W_0 = \text{present welfare function}, \text{and} \]

\[ \hat{R} = \text{a certain amount of resources}. \]

Risk-aversion parameter, $\gamma = 0.5$ in this nation.
(iii) Risk-taker nation: A poor nation may often be a risk taker. Since many agents in the current generation live inhuman lives, such a nation cannot afford to leave more resources unused for the sake of future welfare. Ironically, some developed nations can be risk-takers as well, because of the belief that new innovations will compensate for the current depletion of resources and deterioration of environmental and social qualities. Past experience suggests that new innovations have not only maintained but rather have improved the livelihood of people. Therefore, it is expected that the same trend will continue in the future. Some even expect to escape the Entropy Law by finding new resources elsewhere in the universe.

To the social planner of a risk-taker nation

\[ V \{W_0(\bar{R})\} > V \{E \{W_F(\bar{R})\}\} \]

up to a very high level of present welfare. For such a nation, \( \gamma \) in the sustainability index is high when the nation is in the Sustainable Development Region and low when the nation is in the Unsustainable Development Region.

**Deadweight Loss**

Figure 6.4 shows the constrained and unconstrained use of resources and their possible impacts on present and future well-being with a very simple game tree. The first entry corresponds to the present and the second entry corresponds to the future pay-off respectively.

**Figure 6.4: Constrained and Unconstrained Use of Resources**
The definition of SD indicates that
\[ W(\alpha R, \beta R) \geq W(R, 0), \]
where \(0 < \alpha \leq 1, \beta > 0\) and \(W = A\) social welfare function.

The crucial question is what the desired value for \(\alpha\) is, because \((1 - \alpha)R\) is a sacrifice of the present generation for the future. This can also be considered as a ‘risk-premium’ for the future.

If the present generation does not care for the future generations at all, then pursuing a sustainable development strategy will cause a deadweight loss of \((1 - \alpha)R\). Even if the present generation does care, \((1 - \alpha)R\) is a source of inefficiency because future generations may not need these conserved resources because of the discovery of new resources. What role the conserved resources will play in future well-being is quite uncertain at present time, \(t = 0\).

Whether \(\beta \geq (1 - \alpha)\), that depends on new innovation, discovery of resources, technological progress, population growth rate, etc. Therefore,
\[ W_F = g(\beta R) = g[\eta(u, p)((1 - \alpha)R)], \]
where \(W_F\) is future welfare,
\(p = \) population growth rate,
\(u = \) uncertainty due to other factors and
\(g = \) a non-negative function of \(R (\delta g/\delta R \geq 0)\).

\(\eta\) is a negative function of population growth rate, which indicates a decline in per capita availability of resources. The effect of \(u\) on \(\eta\) is positive if new innovation occurs and it is negative if resources are destroyed due to war, natural calamity and so on. \(\eta = 1\), when technological advancement or new innovation is sufficient just to offset the increased demand due to population growth rate.

Given the uncertainty, at present time, \(t = 0\), optimum conservation of natural and social environments depends on the social planner's risk-perception about future development. This risk-perception is a function of present well-being as well as the current condition of natural and social environments. In defining a sustainable development strategy, the cost or efficiency loss of the present generation must be weighed against the increase in future development potentials.
Some probabilistic measures of future scarcity of resources may be possible under many restrictive assumptions in a particular model. An alternative, however, would be to find a set of criteria to ensure that resources are not being wasted, and that current progress is achieved by maintaining the earth's life support systems above their critical levels. I have made that effort in this paper by defining a sustainability rule.

6.5 Propositions

The Sustainability Rule: $SI \geq 1 \forall \Delta D \geq 0$ and $SI \leq 1 \forall \Delta D < 0$

The numerical value of the Sustainability Index (SI) can be used as a decision criterion, or decision-rule, for making a sustainable development policy. Therefore, the Sustainability Conditions (SC) can be called the Rules for Sustainable Development. By definition, the basic sustainability condition or the primary rule for SD implies that:

(i) The ratio of marginal human development (MH) and marginal damage (MD) to NSE has to be greater than the ratio of the gap between targeted and actual H and the quality of NSE for sustainability, if the stakeholders are risk-neutral and no future discounting is assumed. In notations,

\[
\frac{MH}{MD} \geq \left( \frac{1 - H}{1 - D} \right), \text{ if } \delta = 0 \text{ and } \gamma = 0.5.
\]

(ii) If an economy is presently at the SD region, meeting the sustainability condition ensures that growth trajectory will never cross the critical path. In other words, the nation will not exhaust its NSE prior to reaching its end goals, $H = 1$.

A nation may choose not to follow the rule of SD for a period of time, but that will mean a development path toward the USD region. Therefore, the nation needs to monitor the conditions of its natural and social environments (NSE) periodically. If the nation is already in the USD region, it will be very risky not to follow the rule of sustainable development in its future development endeavours. Therefore, the sustainability index works as a guiding principle. Following propositions\(^6\) specify some important properties of the sustainability index.

\(^6\) Proofs of the propositions can be found in Dewan (1998).
**Proposition I:** On the critical path of SD and in the SD region, an increase in $H$ is always preferable to an equal improvement in the quality of NSE index, if $\delta = 0$ and $\gamma = 0.5$.

**Proposition II:** People prefer higher quality of NSE to higher $H$, if $H \geq 1$.

**Proposition III:** In the unsustainable development region, an increase in $H$ at the cost of an equivalent decline in the quality of NSE index is not a sustainable development, given $\delta = 0$ and $\gamma = 0.5$.

**Proposition IV:** The sustainability condition may require a developing country to slow down its economic development, while allowing a developed country to prosper at the cost of NSE, when the damage index is the same in both countries.

In general, as people's incomes rise they assign increasingly more value on environment and resource conservation. Proposition IV appears to be inconsistent with that notion, but practically it is not. For proposition IV actually implies that a developing country cannot afford to destroy its natural amenities, use up its resource endowments and pollute the environment unrestrictedly. Doing so would seriously constrain the future attainment of higher $H$. It may not be the case for a developed country. Therefore, $SI \geq 1$ may not restrict economic development in a developed country as much as it would in a developing country. This is simply because of the relative high scarcity value of NSE in a poor nation in this circumstance.

If the damage relative to human development is too high, the sustainability condition puts more weight on the quality of NSE, making economic development difficult at the cost of further deterioration of the environmental and social conditions, and natural resource depletion. With a higher state of development, a nation may value the quality of its NSE more. Such differences can be incorporated in the sustainability condition by assuming that $\gamma < 0.5 \forall H > D$ and $\gamma > 0.5 \forall H < D$.

**Proposition V:** (Monotonicity Axiom) If for a given level of $H$, the quality of NSE declines, the numerical value of $SI$ falls.

**Proposition VI:** (i) For a nation in the SD region as $\gamma \to 1$, a one-for-one ratio of a change of $H$ to a change of $D$ is considered sustainable. As $\gamma \to 0$, a little improvement of $H$ at any cost of the environment is sustainable.
(ii) For a nation in the USD region as \( \gamma \rightarrow 1 \), no increase in \( H \) at the cost of NSE is acceptable.\(^68\) As \( \gamma \rightarrow 0 \), a one-for-one ratio of the change of \( H \) to the change of \( D \) is considered sustainable.

Proposition VII: (Non-homogeneity) The sustainability index is not homogeneous of degree zero in \( H \) and \( D \) except on the critical path for SD. Therefore, equivalent changes in \( H \) and \( D \) will affect the numerical value of SI, unless \( H = D \).

Proposition VIII: (Social discounting) Any form of social discounting makes the sustainability condition less stringent.

7. The Sustainability Index (SI) vs. the Cost-Benefit Analysis (CBA)

The sustainability condition (SC) and the feasibility condition (FC) of cost-benefit analysis may not be synonymous due to methodological differences. If the Kaldor-Hicks criterion,\(^69\) which is the basis of CBA, is extended to include the future generations, the sustainability condition will most likely meet the criterion, not the conventional feasibility condition of CBA.

According to the cost benefit analysis (CBA), a project is viable if

\[
\Delta Y_m \geq \Delta D_m.
\]

\[
\Rightarrow \frac{\Delta Y_m}{\Delta D_m} \geq 1,
\]

Where \( \Delta Y_m = \) present value (PV) of the income generated from the project and \( \Delta D_m = \) present value (PV) of the monetary cost of the project.

On the other hand, the sustainability condition is:

\[
\frac{\Delta H}{\Delta D} \geq \frac{1}{1 + \delta} \left( \frac{1 - H}{1 - D} \right)^{\gamma}
\]

To compare CBA and SI,\(^70\) we need to consider several cases:

\(^68\) By using a different structure for the risk-aversion parameter, the same condition can be ascertained for a nation in the SD region. However, that is undesirable, because the development in this nation has been achieved with a relatively cleaner environment.

\(^69\) Kaldor (1939) and Hicks (1940). Boardman, et al. (2006) states the criterion as follows: “A policy should be adopted if and only if those who gain could fully compensate those who will lose and still be better off.”

\(^70\) It is evident that the FC of CBA uses the PV of aggregate benefits and aggregate costs, whereas the SC uses per capita benefits from the project.
Case I

Assume that $H = D$, $\Delta D \geq 0$, $\delta = 0$ and $\gamma = 0.5$, then

$$SI \geq 1 \Rightarrow \frac{\Delta H}{\Delta D} \geq 1$$

$$\Rightarrow \frac{1}{3}\left(\frac{\Delta y^i + \Delta E_d + \Delta L}{\Delta D}\right) \geq 1$$

$$\Rightarrow \frac{1}{3}\left(\frac{\Delta y^i}{\Delta D}\right) + \frac{1}{3}\left(\frac{\Delta E_d + \Delta L}{\Delta D}\right) \geq 1,$$

Where $y^i =$ adjusted per capita real income (PPPS) index, 

$E_d =$ educational attainment index, and 

$L =$ longevity index.

All variables are in $[0, 1]$.

In general, the changes in $E_d$ and $L$ are much slower than the change in $y^i$ (UNDP, 1991). Therefore, $(\Delta E_d + \Delta L) < 2\Delta y^i$.

$$\Rightarrow \frac{\Delta H}{\Delta D} < \frac{\Delta y^i}{\Delta D} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (7.A1)$$

According to Atkinson’s formula\textsuperscript{72} for the utility of income, that the UNDP initially used to calculate adjusted real GDP for HDI, for a nation with per capita real income (PPPS) less than the world average income, $\Delta y = \Delta y_m$ and for a nation with per capita real income (PPPS) greater than the world average income, $\Delta y < \Delta y_m$, where $\Delta y$ and $\Delta y_m$ are changes in adjusted and actual per capita real income respectively. The UNDP’s current methodology\textsuperscript{73} uses the log of per capita income to calculate the GDP index. Therefore, $\Delta y < \Delta y_m$................. (7.A2)

The inequalities, (7.A1) and (7.A2), are significant for deriving relationships between the growth rates of human development (H); adjusted per capita real income (PPPS) index ($y^i$); adjusted and actual per capita real income, $y$ and $y_m$ respectively; and adjusted and actual real income, $Y$ and $Y_m$ respectively. For any positive population

\textsuperscript{71} On the critical path for sustainable development, $H = D$ (measured on a one-point scale).

\textsuperscript{72} See the Human Development Report (1997)

\textsuperscript{73} See the Human Development Report (2005)
growth rate (n), the growth rate of $y_m$ is smaller than the growth rate of $Y_m$. Therefore, 
\[ \frac{\%\Delta H}{\Delta H} < \frac{\%\Delta y}{\Delta y} < \frac{\%\Delta y_m}{\Delta y_m} \forall n > 0 \] .......................... (7.A3)

Multiplying both sides of (7.A2) by the population, we find that
\[ \Delta Y < \Delta Y_m \] .......................... (7.A4)
\[ \Rightarrow \frac{\Delta Y}{\Delta D_m} < \frac{\Delta Y_m}{\Delta D_m} \forall D_m > 0 \]
\[ \Rightarrow \frac{\Delta Y}{\Delta D_m} < CBA \] .......................... (7.A5)
\[ \Rightarrow SI \left( \frac{\Delta Y}{\Delta D_m} \right) \left( \frac{\Delta H}{\Delta D} \right) < CBA \]
\[ \Rightarrow SI < CBA \left( \frac{\Delta D_m}{\Delta Y} \right) \left( \frac{\Delta H}{\Delta D} \right) \] .......................... (7.A6)

In (7.A6), the numerical value of SI is definitely smaller than the numerical value of the
FC of CBA, if \[ \left( \frac{\Delta D_m}{\Delta Y} \right) \left( \frac{\Delta H}{\Delta D} \right) \leq 1 \] or \[ SI \leq \frac{\Delta Y}{\Delta D_m} \] .......................... (7.A7)
In other words, if the monetary cost of a project times the sustainability index is not
greater than the log-adjusted income generated from the project; the SI is certainly more
stringent than the CBA in project-evaluation. This expression can be re-arranged to find
the following condition: \[ \Delta Y_m \geq e^{SI \Delta D_m} \] .......................... (7.A8)
If condition (7.A7) or (7.A8) holds, a project can be feasible in terms of CBA, but it may
not be sustainable. In (7.A6), SI = CBA, if \[ \left( \frac{\Delta D_m}{\Delta Y} \right) \left( \frac{\Delta H}{\Delta D} \right) = \frac{SI}{CBA} \] or \[ CBA = \frac{\Delta Y}{\Delta D_m} \] or
\[ \Delta Y_m = \Delta Y; \] and SI > CBA, if \[ \left( \frac{\Delta D_m}{\Delta Y} \right) \left( \frac{\Delta H}{\Delta D} \right) < \frac{SI}{CBA} \] or \[ CBA < \frac{\Delta Y}{\Delta D_m} \] or \[ \Delta Y_m < \Delta Y. \] As
showed in (7.A4), it is impossible for a change in income ($\Delta Y_m$) to be smaller than or
equal to a change in the log of income ($\Delta Y$); therefore, the sustainability condition is
always more conservative than the feasibility condition of CBA in this case.
From the expression (7.A3), we can derive another relationship between SI and CBA:

$$\%\Delta H < \%\Delta Y_m \quad \forall \ n > 0$$

$$\Rightarrow \frac{\Delta H}{H} \times \frac{\Delta Y_m}{Y_m}$$

$$\Rightarrow \left( \frac{\Delta H}{\Delta D} \right) \times \left( \frac{\Delta Y_m}{\Delta D_m} \right) \times \left( \frac{\Delta D_m}{Y_m} \right) \quad \text{........... (7.A9)}$$

$$\Rightarrow SI < CBA \left( \frac{\Delta D_m}{\Delta D} \right) \left( \frac{H}{Y_m} \right) \quad \text{................. (7.A10)}$$

In (7.A9), the numerical value of SI is definitely smaller than the numerical value of the FC of CBA, if

$$\frac{\Delta D_m}{\Delta D} \times \left( \frac{H}{Y_m} \right) \leq 1 \text{ or } \left( \frac{\Delta D_m}{\Delta D} \right) \times \left( \frac{H}{Y_m} \right) \leq 1 \quad \text{........... (7.A11)}$$

In other words, if the ratio of monetary damage to real income is not greater than the ratio of physical damage to the level of human development, the SC is more conservative than the FC of CBA. Alternatively, if the ratio of monetary to physical damage is not greater than the constant, $\frac{Y_m}{H}$, the SI < CBA. If, however, the opposite is true, SI $\geq$ CBA.

**Case II**

Assume that $H > D$, $\Delta D \geq 0$, $\delta = 0$ and $\gamma = 0.5$, then

$$SI \geq 1 \Rightarrow \frac{\Delta H}{\Delta D} \geq \left( \frac{1 - H}{1 - D} \right)$$

$$\Rightarrow \frac{\Delta H}{\Delta D} \geq 1 - X, \text{ where } X = \left( \frac{H - D}{1 - D} \right) > 0 \quad \text{.............. (7.B1)}$$

The same as Case I, if condition (7.A7) or (7.A8) holds, a project can be feasible in terms of CBA, but it may not be sustainable. The sustainability condition in this case is more stringent than the feasibility condition of CBA; however, it is not as stringent compared to the sustainability condition in Case I.

From the expression, (7.A9), we can find

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74 In the sustainable development region, $H > D$. 

41
\[
\left( \frac{\Delta H}{\Delta D} \right) \left( \frac{\Delta D}{H} \right) \frac{1 - D}{1 - H} < \left( \frac{\Delta Y_m}{\Delta D_m} \right) \left( \frac{\Delta D_m}{Y_m} \right) \frac{1 - D}{1 - H}
\]

\[\Rightarrow SI < CBA \left( \frac{\Delta D_m}{\Delta D} \right) \left( \frac{H}{Y_m} \right) \frac{1 - D}{1 - H} \] \hspace{1cm} (7.B2)

In (7.B2), the numerical value of SI is definitely smaller than the numerical value of the FC of CBA, if

\[\left( \frac{\Delta D_m}{\Delta D} \right) \left( \frac{H}{Y_m} \right) \frac{1 - D}{1 - H} \leq 1\]

\[\Rightarrow \left( \frac{\Delta D_m}{\Delta D} \right) \left( \frac{H}{Y_m} \right) \leq \frac{1 - H}{1 - D} \] \hspace{1cm} (7.B3)

\[\Rightarrow \left( \frac{\Delta D_m}{\Delta D} \right) \left( \frac{H}{Y_m} \right) \leq 1 - X \] \hspace{1cm} (7.B4)

**Case III**

Assume that \( H < D, \Delta D \geq 0, \delta = 0 \) and \( \gamma = 0.5 \), then

\[SI \geq 1 \Rightarrow \frac{\Delta H}{\Delta D} \geq \frac{1 - H}{1 - D}\]

\[\Rightarrow \frac{\Delta H}{\Delta D} \geq 1 + Z, \text{ where } Z = \left( \frac{D - H}{1 - D} \right) > 0\]

\[\Rightarrow \frac{\Delta H}{\Delta D} \gg 1\]

The same as Case I, if condition (7.A7) or (7.A8) holds, a project can be feasible in terms of CBA, but it may not be sustainable. The sustainability condition in this case is not only more stringent than the feasibility condition of CBA; it is also more stringent than the sustainability conditions in the other two cases.

From the expression (7.B3), we can find

\[\left( \frac{\Delta D_m}{\Delta D} \right) \left( \frac{H}{Y_m} \right) \leq 1 + Z \] \hspace{1cm} (7.C1)

If condition (7.C1) holds, the numerical value of SI is definitely smaller than the numerical value of the FC of CBA.

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\(^{75}\) In the unsustainable development region, \( H < D \).
The above conditions lead to the following propositions:

**Proposition I:** If \( SI \leq \frac{\Delta Y}{\Delta D_m} \) or \( \Delta Y_m \geq e^{SI*\Delta D} \), the sustainability condition is more conservative than the feasibility condition of CBA.

**Proposition II:** Unlike the feasibility condition of CBA, the sustainability condition (SC) is different in different sustainable development regions. The SC is the most stringent in the unsustainable development region and the least stringent in the sustainable development region.

**Proposition III:** The sustainability condition is more conservative than the feasibility condition of CBA, if \( \left( \frac{\Delta D_m}{\Delta D} \right) \left( \frac{H}{Y_m} \right) \leq 1 + K \), where \( K = 0, -X \) or \( Z \) depending on whether the economy is on the critical path for SD, in the SD region or in the USD region respectively.

One of the reasons for the sustainability condition to be more stringent than the feasibility condition of CBA is probably because the actual damage to NSE is often more than that reflected by the monetary measure of the damage. It is also possible, but is very unlikely, that the monetary damage would overstate the actual damage. If that happens, the sustainability condition may allow a monetary loss.\(^7\) Besides the discrepancy between monetary valuation of damage and the physical damage, the relationship between changes in human development index is not proportional to the income generated from a project, which is another reason why the two conditions will most likely differ.

To be more conservative or risk-averse one may suggest that a project be undertaken if, and only if, it meets both the feasibility condition of CBA and the sustainability condition in all cases and in all scenarios. Not only that, a project should be sustainable both nationally and locally. If that means a sub-optimal choice based on CBA, the deadweight loss can be calculated, and that can be considered as the premium for uncertainty; or the cost of conservation or sustainable development.

\(^7\) It has been discussed earlier in this paper that money is not a perfect measure for the concerned variables.
8. Further Extension

Environmental sustainability is one of eight millennium development goals\(^{77}\) that 191 UN member states have pledged to meet by 2015. That shows the relevance of this theoretical paper. It shows an integration mechanism of sustainability indicators for practical use. In order to construct a uniform index for all countries, my future research will focus on identifying a more rigorous set of indicators for the sustainability index (SI) based on HDR, UNCSD indicators, EPI, GPI etc. However, we must recognize that the sustainability issues are different in different parts of the world, and therefore, a universally accepted algorithm should have flexibility to include diverse sets of indicators and policy parameters. Simulation technique will be used to find desired values and trends of sustainability indicators, and to evaluate sustainability under different policy regimes. Based on past time series data, I shall compute sustainability indices for a number of countries, and show their trends along with the growth rates of GDP, ISEW and GPI. How different paths of economic development such as the industrial revolution, export-led growth, or agro-based growth; and different political systems affect the index that will also be explored. Where possible, I shall also assess the performance of SI against EPI. At the micro level, I shall use the sustainability condition and the feasibility condition of CBA for project evaluation to calculate the possible deadweight loss.

\(^{77}\) UN (2005)
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