Lecture 2
Sustainable Development and Green National Accounts
Partha Dasgupta
Santa Fe Institute
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The article contains a large set of references.
In evaluating an economy, there are five questions we can ask: (A) How is the economy doing? (B) How has it performed in recent years? (C) How is it likely to perform under "business as usual"? (D) How is it likely to perform under alternative policies? (E) What policies should be pursued there?
National income accounts offer information relevant for answering (A), although it does so in an unsatisfactory way. Policy evaluation, including project evaluation, is a way to answer questions (D) and (E), which was the subject of Lecture 1. The idea is to evaluate an economy at a point in time before and after a hypothetical perturbation has been made to it. In contrast, the literature on "sustainable development" answers questions (B) and (C) by evaluating economic change when the perturbation is the passage of time itself. That's the topic for this lecture.
Question (A) stands apart from questions (B) to (E), at least if conventional practice among national income statisticians is any guide. For it is common practice to summarize the state of an economy by its GDP, or equivalently its (gross) domestic income.

Why GDP is inadequate for answering (B)-(E)?
Time is continuous, \( t \geq 0 \). We consider a deterministic world. Let \( \mathbf{C}(t) \) be an \( M \)-vector of consumption services at time \( t \). \( C_j(t) \) is the \( j \)th consumption service \( (j = 1,2,\ldots,M) \). There are \( N \) capital assets. \( K_i(t) \) is the quantity of the \( i \)th asset \( (i = 1,2,\ldots,N) \). An economic forecast at \( t \) is the infinite sequence \( \{\mathbf{C}(s), \mathbf{K}(s)\} \) for \( s \geq t \).
Types of assets: (i) Reproducible capital (buildings, roads, machines, vehicles); (ii) Human capital (skills, knowledge, health); (iii) Publicly available knowledge (science, mathematics, technology); (iv) Natural capital (ecosystems, oil and natural gas); (v) Institutions (sometimes called "social capital"). For reasons we will see presently, we keep (v) separate from (i)-(iv) and regard the latter to comprise the $N$ capital assets.
As in Lecture 1, let $V(t)$ denote social well-being at $t$. $V(t)$ is taken to be of the Utilitarian form

$$V(t) = \int_t^\infty [U(C(s), K(s)) e^{-\delta(s-t)}] ds,$$

where $\delta (> 0)$ is the rate of time discount. We assume that the integral exists. Expression (2) gives us an ethical calculus with which we address questions (B)-(E).
Sustainable Development:
"... development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland Commission, 1987).
NB: (i) "sustainable development" requires that relative to their populations, each generation should bequeath to its successor at least as large a productive base as it had itself inherited.

(ii) The requirement is derived from a relatively weak notion of intergenerational equity. Sustainable development demands that future generations have no less of the means to meet their needs than we do ourselves. It demands nothing more; it doesn't, for example, demand that development be optimal or just.
Question: How is a generation to judge whether it is leaving behind an adequate productive base for its successor?

Tracking GDP or the United Nations' Human Development Index (HDI) won't do. Why?
Starting with $K(\theta)$ and the economy's institutions, let \{ \{ C(t), K(t) \} \} be an economic forecast.

The Brundtland Commission defined sustainable development in terms of the determinants of social well-being. We define it in terms of social well-being itself:
Definition 1: An economic programme \( \{C(t), K(t)\} \) displays sustainable development at \( t \) if

\[
\Delta V(t) \geq 0,
\]

(where \( \Delta V(t) \) should be read \( \frac{dV(t)}{dt} \)). (2)

NB: \( V(t) = V(K(t), t) \). At \( t, K(t) \) and \( t \) are the state variables.
Valuing Goods and Services

Evaluating an economy requires that we value goods and services from a societal point of view. The social values of goods and services are called shadow prices. Let social well-being be the numeraire.

Shadow Prices

Definition 2. Suppose at date t an economy is awarded an additional unit of a commodity free of charge. The commodity's shadow price is the resulting change in social well-being.
Formally: Let $q_j(t)$ denote the shadow price of consumption good $j$ at $t$. Then

$$q_j(t) = \frac{\partial U(C(t), K(t))}{\partial C_j(t)}, \quad j = 1, 2, \ldots, M.$$  

(3)

Let $p_i(t)$ be $i$th capital asset's shadow price. Then, on using (1), we have

$$p_i(t) = \frac{\partial V(K(t), t)}{\partial K_i(t)}, \quad i = 1, 2, \ldots, N.$$  

(4)

Time to be a capital asset too, measured in terms of the value of waiting. If institutions improve (alternatively, deteriorate) exogenously, time reflects institutional capabilities (social capital). If $r(t)$ is the shadow price of $t$,

$$r(t) = \frac{\partial V(K(t), t)}{\partial t}.$$  

(5)
3 pieces of information are required for estimating shadow prices:

(i) A descriptive model of the economy.
(ii) The size and distribution of the economy's capital assets.
(iii) A conception of social well-being.

Requirements (i) and (ii) are the basis for estimating the changes that take place in the allocation of resources if an additional unit of the asset is made available free of charge. Requirement (iii) is the basis for placing a value on that change.
Comments on $p_i(t)$:
(1) It is a function of the stocks of all assets. Moreover, it depends not only on $K(t)$, but on all $K(s)$, $s > t$.
(2) Future scarcities of natural capital are reflected in $p_i(t)$, implying that the $p_i(t)$'s are functions of the degree to which various assets are substitutable for one another, not only at $t$, but at all subsequent dates as well.
(3) If $\delta$ is large (low), the influence on today's shadow prices of future scarcities would be attenuated (large). Recall Lecture 1.
**Definition 3**: the economy's comprehensive wealth at \( t \) as:

\[
W(t) = r(t)t + \sum_i [p_i(t)K_i(t)].
\] (6)

Why should we be interested in comprehensive wealth? The reason is:

**Proposition 1**: A small perturbation to an economy increases (resp., decreases) social well-being if, and only if, holding shadow prices constant, it increases (resp., decreases) comprehensive wealth.
Proof: Let $\Delta$ denote a small perturbation. Assuming $V$ is differentiable, we have

$$
\Delta V(t) = [\partial V/\partial t] \Delta t + \Sigma[\partial V/\partial K_i(t)] \Delta K_i(t).
$$  \hspace{1cm} (7)

Now use (4) and (5) to re-express (7) as:

$$
\Delta V(t) = r(t) \Delta t + \Sigma p_i(t) \Delta K_i(t). \text{ QED}
$$  \hspace{1cm} (8)
Write \( I_i(t) = p_i(t)\Delta K_i(t) \). Then equation (8) can be expressed as
\[
\Delta V(t) = r(t)\Delta t + \sum [I_i(t)].
\] (9)
The RHS of equation (9) is the *comprehensive investment* that accompanies the perturbation to the economic programme. This means Proposition 1 can be re-stated as:
Proposition 2: A small perturbation to an economy increases (resp., decreases) social well-being at \( t \) if, and only if, the comprehensive investment at \( t \) that accompanies the perturbation is positive (resp. negative).
NB: If the perturbation $\Delta$ is conducted at a moment in time, its evaluation is called "social cost benefit analysis". In contrast, if the perturbation is the passage of time itself, the evaluation involves testing for "sustainable development". Conclusion: Two seemingly different exercises amount to the same thing.
What does comprehensive investment measure? For simplicity, assume $M = 1$ and $U = U(C)$. Write $I(t) = \sum [I_i(t)]$.

**Proposition 3:** $I(t) = \int_0^{\infty} [U'(C(\tau))\Delta C(\tau)e^{-\delta(\tau-t)}]d\tau$. (10)

So, comprehensive investment is a measure of the present discounted value of the changes in consumption that are brought about by it. Proposition 3 is the basis of social cost-benefit analysis.
Global Public Goods

What of public goods (e.g., carbon concentration in the atmosphere)? Let $G(t)$ be the stock of a global public good at $t$. $G$ is an argument in the $V$-function of every country. Let $K_m(t)$ be the vector of assets owned by residents of country $m$. If $V_m$ is social well-being in $m$, $V_m(t) = V_m(K_m(t), G(t), t)$.  

(11)
Let $p_m(t)$ be the vector of shadow prices of all the assets owned by residents of $m$, and $g_m(t) = \frac{\partial V_m(t)}{\partial G(t)}$. $G$ may well be an economic "good" for countries in the temperate zone and an economic "bad" in the tropics. If so, for the former, $g_m > 0$; for the latter, $g_m < 0$. 
Let $E_m(t)$ be the net emission rate from country $m$ and $E(t)$, the net aggregate emission. It follows that
\[ \Delta G(t) = \sum_m (E_m(t)) = E(t). \]  \hspace{1cm} (12)

Write
\[ I_m(t) = \sum_i p_{mi}(t) \Delta K_{mi}(t). \]  \hspace{1cm} (13)

Using (12), (8) becomes,
\[ \Delta V(t) = r_m(t) \Delta t + I_m(t) + g_m(t) [\sum_m E_m(t)]. \]  \hspace{1cm} (14)
Population Growth

Population is a capital asset. Population growth is usually assumed to be exogenous. For simplicity assume that the size of the population, \( P(t) \), is the stock of the demographic asset. It may seem intuitive that the way to tease exogenous growth in population out of \( \partial V/\partial t \) is to define comprehensive wealth in *per capita* terms and re-express Proposition 1 accordingly. It can be shown that to be a correct move only under very special circumstances.
## The Progress of Nations

<table>
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<tr>
<th>Country/Region</th>
<th>% annual growth rate 1970-2000</th>
<th>I/Y*</th>
<th>population (per c.)</th>
<th>TFP&quot;</th>
<th>wealth (per c.)</th>
<th>GDP</th>
<th>ΔHDI**</th>
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<tbody>
<tr>
<td>Africa</td>
<td>-2.1</td>
<td>2.7</td>
<td>0.1</td>
<td>-2.8</td>
<td>-0.1</td>
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<tr>
<td>Bangladesh</td>
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<td>2.2</td>
<td>0.7</td>
<td>-0.8</td>
<td>1.9</td>
<td>+</td>
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<tr>
<td>India</td>
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<td>2.0</td>
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<td>-0.4</td>
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<td>13.3</td>
<td>2.2</td>
<td>0.5</td>
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<td>1.9</td>
<td>+</td>
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<tr>
<td>Pakistan</td>
<td>8.8</td>
<td>2.7</td>
<td>0.4</td>
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</tr>
<tr>
<td>China</td>
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<td>1.4</td>
<td>3.6</td>
<td>4.8</td>
<td>7.8</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

* comprehensive investment as share of GDP (average over 1970-2000)
" total factor productivity
** change in HDI between 1970-2000

Adapted from Dasgupta (2000) and Arrow et al. (2004).