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ENVIRONMENTAL SUSTAINABILITY AND ECONOMIC DEVELOPMENT: COST BENEFIT ANALYSIS FOR SUSTAINABLE DEVELOPMENT

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Environmental Sustainability and Economic Development: Cost Benefit Analysis for Sustainable Development[1]

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Abstract

Sustainable development, environmental sustainability, green economies and green growth are issues which are of great importance for both the research and the policy agenda. The present paper clearly defines the concepts of sustainability and environmental sustainability and provides a conceptual framework for developing sustainability-founded cost benefit rules. It shows that a certain policy cannot necessarily simultaneously satisfy sustainable development and environmental sustainability objectives, the development of green economies, and the attainment of development or green growth. This is important for decision makers because it suggests using more than one criterion depending on the combination of the objectives to be pursued. The cost benefit rules presented in this paper could provide a basis for a clear distinction among objectives and for project selection mechanisms that promote single or multiple objectives.

Keywords: Sustainable development, wellbeing, comprehensive investment, accounting prices, cost benefit analysis, environmental sustainability, green economies, green growth.

1 Introduction

The study of issues such as environmental sustainability and economic development, and their links, interrelations and compatibility as targets to be attained by modern societies, brings forth a number of fundamental questions which need to be addressed. The now widely accepted definition of sustainability provided by the Brundtland Report is "…development which meets the needs of the present without compromising the ability of future generations to meet their own needs…" This definition, although intuitive and well understood causes other fundamental questions to emerge.

How can we know whether or not the actions of present generations will undermine the wellbeing of future generations and how can we measure the wealth of nations? How can we tell whether the development of a country is sustainable or not? What policies promote sustainability and what can firms and individuals do to help achieve sustainability? For example, how can universal access to modern energy services promote development and sustainability targets?

Furthermore how can we assess whether the natural and environmental resources of a country are being used in a way that will provide fair benefits across the same or future generations? And finally and probably most importantly, even if we can set attainable sustainability objectives and associated policies, are these targets and policies compatible with stabilization, development and growth objectives? Is green growth a desirable and attainable target? Would a green economy help to stabilize the economies during recessions?

These are questions that have concerned economists since the 1970s and they remain, with even greater intensity, at the forefront of research and policy making. In the current period, with economic recession plaguing large areas of the world and the sustainability of debt being a major concern for numerous countries, the issue of intergenerational fairness – what kind of a situation we leave to future generations – is more relevant than ever.

The purpose of the present paper is not of course to provide answers to all the questions above; this would be an impossible task. My purpose is rather to identify the main issues, explore ways of analyzing them and trace conceptual frameworks for policy design that will be compatible with sustainability. In particular I will concentrate on describing a cost-benefit analysis framework which is consistent with the sustainability objective.

Cost benefit analysis (CBA) provides, in broad terms, a systematic way of comparing the costs and benefits of a project so that project selection promotes the efficient allocation of scarce resources. CBA has been traditionally regarded as a tool for promoting economic development, by helping to select the correct development-promoting projects. The methodology has been extensively applied since the end of the second world war. Development, in the early stages of CBA development and application, was mainly thought of in terms of GDP per capita, along with a few important indicators related to health or education. The primary objective of CBA was for a developing country to promote projects to improve its competitive position in world markets. Thus CBA introduced a new set of prices called accounting prices, which were based on world prices. Accounting prices were used to replace distorted domestic prices, so that the correct signals for being competitive in world markets were given.

When we move however from traditional development objectives to sustainability objectives, the CBA framework and in particular the concept of accounting prices should be modified, since the main objective now is not competitiveness in world markets, but sustainability and these two objectives are not identical. This means that the new accounting prices - the sustainability accounting prices - should provide the correct signals so that CBA selects projects that promote sustainability.

However to start building, a systems of sustainability accounting prices (SAP) we need an operational definition of the sustainability objective that would allow a meaningful definition of SAP. Thus is the next section we review definitions of sustainability and choose the one that is helpful in defining SAP.

2 Defining Sustainability

In an attempt to make the definition of sustainable development operational, so that empirical estimations and policy design would be facilitated a number of definitions which are auxiliary to the original Brundtland definitions have been developed.

The most prevailing of these definitions associate sustainable paths with:

1. Achieving constant utility (Solow, 1974; Hartwick, 1977).

2. Having the representative agent's utility (well being) $U(t)$, not exceeding the maximum level of utility $U^m(t)$ which can be sustained forever from t onwards given the capital stocks existing at t (Pezzey, 2004). This definition is implied by, but does not imply, the well known condition that the agent's utility is forever non-declining from t onwards (Pearce et al., 1990; Pezzey, 1992, 1997).

3. Non-declining social welfare (NDSW) or equivalently non-declining intergenerational wellbeing, that is, avoiding any decline in intergenerational social welfare defined in terms of a Ramsey–Koopmans social welfare functional (R–K SWF), either from time t forever onwards, or much less demandingly, just at time t (Riley, 1980; Dasgupta and Mäler, 2001; Pemberton and Ulph, 2001; Arrow et al., 2003).

This last definition of non-declining social welfare or non-declining wellbeing, which has been studied in detail and further elaborated by Arrow et al. (2012), has been accepted as an operational definition of sustainable development and it is this definition that will be used as a basis for the rest of this paper.

In the context of the non-declining welfare or wellbeing criterion, sustainable development can be defined equivalently as the maintenance of the economy's productive base. That is, each generation should bequeath to each successor at least as large a productive base as it inherited from its predecessors. This definition is compatible with the non-declining genuine investment (or savings) definition of sustainable development formulated by the World Bank (Hamilton, 1994, 1999) and, as will be shown later, can be used as a basis for developing the sustainability promoting cost-benefit rule.

The productive base which determines social wellbeing or comprehensive wealth consists of the economy's assets which may include Manufactured Capital, Human Capital and Knowledge, Natural Capital, Social Capital, and Health Capital. Therefore, since the productive base is in principle measurable, while "needs" which is central in the Brundtland definition is not an easily defined and measured quantity, the definition of sustainability in terms of non-declining wellbeing and productive base is an operational definition.

Having settled on an operational definition for sustainability, the next important issue is how to value the assets that constitute the productive base in a way that is consistent with economic theory and at the same time provides the necessary structure and information to conduct sustainability CBA. In the context of SAP we need to define accounting prices for each type of asset so that when a project is undertaken, and the impact of the project is to increase or use one or more assets, we will be able to value the changes and provide meaningful cost benefit comparisons.

Definition 1 *In the context of sustainability, an accounting price for an asset measures the change in the present value of future wellbeing from a change in the stock of this asset.*

Thus if the net change in the value of assets participating in the productive base due to a project is positive when valued at accounting prices, then this project promotes the objective of sustainability.

A concept closely related to wellbeing is the concept of genuine investment. Genuine investment is defined as the sum of the investment in the capital assets defined above valued at accounting prices. As has been shown (e.g. Arrow et al., 2003, 2012) positive genuine investment increases wellbeing and comprehensive wealth, and thus if genuine investment is non-decreasing over time, then wellbeing and social welfare is also non-decreasing and development is sustainable. This is the weak sustainability concept since it allows for any of the assets to increase and decrease as long as the net change valued at accounting prices is positive.

3 Sustainability Cost-Benefit Analysis

In this section we are going to use the definition of sustainability given above to provide cost-benefit rules which are compatible with the sustainability objective. To do this we need a model of the economy with a structure that is adequate for incorporating into the analysis issues such as climate change, human capital, energy derived from fossil fuel and/or renewables, or ecosystems services. This economy is described in the following section.

3.1 Sustainability Criteria for a Model Economy

Consider an economy where output is produced by physical (or produced) capital, labour which embodies human capital, energy produced from fossil fuel, which is a depletable resource, and/or renewables and ecosystem services. This is A quite general representation that captures many aspects of contemporary market economies. The structure can be described in the following steps:

- Physical capital, human-capital-embodying labour input, fossil fuels, renewables, and services derived by ecosystems are combined to produce aggregate output which will be denoted by $Y(t)$. This is the GDP.
- The use of fossil fuels generates greenhouse gas (GHG) emissions which accumulate as a stock.
- The stock of GHGs creates damages which reduce the utility of the individuals and degrades the ecosystems, deteriorating thus their services. These are the damages from climate change.
- The stock of GHGs can be reduced by reducing the use of fossil fuels, which is mitigation, or by costly carbon capture and storage (CCS) activities.
- Energy can be produced by renewables to substitute energy produced by fossil fuel.
- Renewable capacity or stock accumulates by costly investment in renewables.
- Climate change damages can be directly reduced by costly adaptation.
- Human capital accumulates by devoting a part of individuals' non-leisure time to human capital accumulation and the rest to the production of output.
- Adaptation capital and CCS capital accumulates through investment in adaptation and CCS.
- Ecosystems which are regarded as an aggregate stock that generates a flow of useful services, is reduced through the services it provides (e.g., provisioning services such as harvesting) and through the deterioration of climate change. The stock is enhanced by natural regeneration processes and by costly human restoration activities.

- The produced output in this economy is distributed among consumption, net investment in physical capital and its depreciation, the cost of renewables and fossil fuel extraction, adaptation expenses, CCS expenses, and ecosystem restoration expenses.

- Social welfare at each point of time t is determined by the utility derived from consumption, less damages due to climate change.

- Intergenerational wellbeing or welfare at any point in time t is the discounted sum of the future flow of social welfare.

In this model economy the productive base consists of the existing assets at any given time t which are: physical or produced capital $K(t)$, stock of fossil fuels $X(t)$, stock of renewables (e.g. wind power or photovoltaic capacity) $R(t)$, human capital $h(t)$, the ecosystem $S(t)$, the stock of GHGs $E(t)$, the stock of adaptation capital $A(t)$ (e.g. dams to protect against sea level rising) and the stock of CCS capital $C^s(t)$ equipment and installations that allow CCS. These stocks evolve dynamically through time given historical, natural and economic laws of motion.

Following Arrow et al. (2003, 2012) we can define as an allocation mechanism, not necessarily optimal, a set of rules (or mappings) that determine the basic economic decisions regarding flows in terms of the assets of the productive base. Note that changes in flows refer either to changes in the consumption stream, or to fossil fuel extraction or investment in renewables, human capital, abatement or CCS capacity and ecosystem restoration. Thus the basic flows in our economy are: consumption $C(t)$, fossil fuel extraction, $q(t)$, investment in renewables $r(t)$, proportion of non-leisure time devoted to human capital accumulation $1-u(t)$, which is investment in human capital, use of ecosystem services $s(t)$, investment in adaptation capacity $\alpha(t)$, investment in CCS capacity $c^s(t)$ and investment related to ecosystem restoration $i(t)$. These are basically the decision variables, or instruments or controls which when changed can change the development path of the economy. Changes in the instruments will satisfy the sustainability criterion if they keep or move the economy to a sustainable path. An allocation mechanism will determine the above instruments as functions of the assets of the productive base. The structure of the economy is described in detail in the Appendix.

We can also define social welfare at each point of time $W(t)$ in terms of utility from consumption $U(C(t))$ and damages from climate change after adaptation $\mathcal{D}(E)$. The interconnections among the assets and the instruments in the economy make social welfare a function of the productive base.

Let us denote by $V(t)$ intergenerational welfare, recalling that $V(t)$ is the discounted flow of future $W(t)$. Then it is clear that intergenerational welfare will be a function of the entire future time paths of the assets comprising the productive base of the economy. A small perturbation in an instrument, for example an investment $\Delta\alpha(t)$ will change the present and future adaptation capacity by some $\Delta A(t)$, which will in turn change the flow of $W(\tau)$, $\tau \geq t$, and therefore will change intergenerational welfare by $\Delta V(t)$. The rate of change $\frac{\Delta V(t)}{\Delta A(t)}$ will be the accounting price for adaptation capacity. In the same way we can define the accounting prices for the rest of the assets comprising the productive base of the economy. If we consider a very small, infinitesimal change in an asset, then the accounting price of this asset at time t will be defined as (see also Arrow et al., 2003)

$$V_{\Omega}(t) = \lim_{\Delta\Omega(t)\to 0} \frac{\Delta V(t)}{\Delta\Omega(t)} = \frac{\partial V(t)}{\partial\Omega(t)}, \quad \Omega = K, X, R, h, S, E, A, C^s. \tag{1}$$

It can easily be shown (see the Appendix) that since intergenerational well-being depends on the productive base, its rate of change will be

$$\begin{aligned} \Delta V(t) \quad = \quad & [V_K(t)\,\Delta K(t) + V_X(t)\,\Delta X(t) + V_R(t)\,\Delta R(t) + \\ & V_h(t)\,\Delta h(t) + V_S(t)\,\Delta S(t) + V_E(t)\,\Delta E(t) + V_A(t)\,\Delta A(t) + \\ & V_{C^s}(t)\,\Delta C^S(t)]\Delta t + \left(\frac{\partial V(t)}{\partial t}\right)\Delta t. \end{aligned} \tag{2}$$

Note that the terms $\Delta\Omega(t)$, $\Omega = K, X, R, h, S, E, A, C^s$ denote net investment in the corresponding asset, while the term $\frac{\partial V(t)}{\partial t}$ reflects explicit time dependencies of the allocation mechanism such as exogenous total factor productivity (TFP) changes. Then, according to the sustainability definition, the economy will be sustainable at time t if

$$\Delta V(t) \geq 0. \tag{3}$$

Genuine or comprehensive investment at time t is defined as the aggregate value of all net investment of the economy valued at accounting prices.

If the allocation mechanism does not depend on time explicitly, that is, it is autonomous, then $\frac{\partial V(t)}{\partial t} = 0$ and genuine investment at time t, denoted by $G(t)$, is the right hand side of (2), or

$$\begin{aligned} G(t) = {} & [V_K(t)\Delta K(t) + V_X(t)\Delta X(t) + V_R(t)\Delta R(t) + \\ & V_h(t)\Delta h(t) + V_S(t)\Delta S(t) + \\ & V_E(t)\Delta E(t) + V_A(t)\Delta A(t) + V_{C^s}(t)\Delta C^S(t)]\,\Delta t. \end{aligned} \tag{4}$$

As before the economy will be on a sustainable path at time t if

$$G(t) \geq 0. \tag{5}$$

If there is an exogenous time dependent drift due to exogenous TFP changes, which implies that $\frac{\partial V(t)}{\partial t} = TFP(t)$, then genuine investment will be

$$\begin{aligned} G(t) = {} & [V_K(t)\Delta K(t) + V_X(t)\Delta X(t) + V_R(t)\Delta R(t) + \\ & V_h(t)\Delta h(t) + V_S(t)\Delta S(t) + V_E(t)\Delta E(t) + V_A(t)\Delta A(t) + \\ & V_{C^s}(t)\Delta C^S(t)]\,\Delta t + TFP(t)\,\Delta t \end{aligned} \tag{6}$$

and the economy will be on a sustainable path at time t if $G(t) \geq 0$.

A central part of the sustainability definition which makes possible the evaluation of policies in terms of the sustainability objective is accounting prices. Assume that in a country during a year Δt the physical capital increased by $\Delta\hat{K}$, the stock of fossil fuels was reduced by $\Delta\hat{X}(t)$, stock of ecosystems was reduced by $\Delta\hat{S}(t)$ and the rest of the assets remained constant. Then, assuming that accounting prices remain approximately constant, the country will be sustainable at this year if

$$\hat{G}(t) = V_K(t)\Delta\hat{K} - V_X(t)\Delta\hat{X}(t) - V_S(t)\Delta\hat{S}(t) > 0.$$

The country will not be sustainable if $\hat{G}(t) < 0$.

The above definitions can also be used to define comprehensive wealth as:

$$\begin{aligned} V\left(t\right) &= V_K\left(t\right)K\left(t\right) + V_X\left(t\right)\Delta X\left(t\right) + V_R\left(t\right)R\left(t\right) + \\ & V_h\left(t\right)h\left(t\right) + V_S\left(t\right)S\left(t\right) + V_E\left(t\right)E\left(t\right) + V_A\left(t\right)A\left(t\right) + \\ & V_{C^s}\left(t\right)C^S\left(t\right) + TFP\left(t\right)t. \end{aligned} \tag{7}$$

Thus comprehensive wealth is the total value of a country's assets valued at accounting prices.

It should be clear that more assets can enter the definition of comprehensive wealth (7) and the sustainability criteria (3) or (5), such as health capital, institutions, or other resources like water, fish biomass, or forests, provided that appropriate links can be modelled and the appropriate data can be collected for estimation purposes. If comprehensive wealth for a country can be estimated for a number of years, then if the time series is not declining with respect to time we may infer that the economy is on a sustainable path. On the contrary if the time series is declining, then the economy is not on a sustainable path. Arrow et al. (2012) provides estimates of comprehensive wealth for the United States, China, Brazil, India and Venezuela.

3.2 Environmental Sustainability

Having defined sustainability criteria for the whole economy, it is possible to define sustainability criteria for specific sectors. Regarding environmental sustainability the approach would be the expansion of the resource sector to include in the productive base depletable resources X, renewable resources R^R, water resources W^R, ecosystems providing nonmarket benefit flows C^s, and stock of pollutants generating negative externalities, P. The accounting prices for these stocks will reflect the change in intergenerational welfare from a small change in the stock of the environmental asset, or $V_\Omega = \frac{\Delta V}{\Delta}$, $\Omega = X, R^R, W^R, C^s, P$. According to our analysis above the economy will be environmentally sustainable at time t if

$$G^E\left(t\right) = \left[V_X\Delta X + V_{R^R}\Delta R^R + V_{W^R}\Delta W^R + V_{C^s}\Delta C^s + V_P\Delta P\right]\Delta t \geq 0. \tag{8}$$

Since however this is a partial criterion, environmental sustainability at time t does not necessarily imply sustainability at time t.

3.3 Cost Benefit Analysis for Sustainability

Having defined a criterion that allows us to check whether the economy is on a sustainable path, the next step is to develop cost benefit rules that will be consistent with promoting projects which satisfy the sustainability criterion. Given the structure of the economy and the links between assets and instruments, comprehensive investment will depend in general on the assets the available instruments and accounting prices. Thus in general

$$\begin{aligned} G(t) &= \Psi\left(K, X, R, h, S, E, A, C^s; C, q, r, u, \alpha, c^s, i;\right. \\ &\qquad \left. V_K, V_X, V_R, V_h, V_S, V_E, V_A, V_{C^s}\right). \end{aligned} \tag{9}$$

An investment will be represented by a small change in an instrument. Thus investment in CCS can be represented by $\Delta c^s(t)$, which indicates that the current flow of CCS expenses changes by a small amount at time t, and this change will in turn change the stock of CCS capacity. This investment will be acceptable as a sustainability promoting investment if

$$\Delta G(t) = \Psi'_{c^s} \Delta c^s(t) \geq 0, \tag{10}$$

where Ψ'_{c^S} stands for the change of the comprehensive or genuine investment due to a change in CCS activity. Criterion (10) indicates that the investment in CCS will promote sustainability if it increases genuine investment and thus can be accepted under a sustainability based CBA. It should be noted that a positive $\Delta G(t)$ is compatible with a negative $G(t)$. This situation would mean that while the economy is not sustainable at t, the specific investment promotes sustainability since it increases comprehensive investment. If $G(t) + \Delta G(t) > 0$, then the specific investment made the economy sustainable at t. In a similar way an investment in renewable energy capacity will be accepted on sustainability grounds if

$$\Delta G(t) = \Psi'_r \Delta r(t) \geq 0. \tag{11}$$

The sustainability cost-benefit criterion could be quite complex, despite the formal simplicity of (10) or (11), because it depends on accounting prices and the interrelations among assets and instruments in the economy. On the other hand, if the accounting prices have been estimated and the links are identified, the application of the rule is simple and intuitive. A detailed derivation of the sustainability accounting prices and the cost benefit rule for our model economy are presented in the Appendix.

4 Sustainability and Development

Traditional CBA (e.g. Brent, 1990) would value a project's costs and benefits in accounting prices which are based on world prices seeking to promote economic development through the attainment of competitiveness in world markets. In particular conversion factors are determined using as a basis the ratio of world to domestic prices. World and domestic prices are expected to deviate due to domestic distortions and the use of conversion factors to convert domestic prices to world prices, shows which projects promote the country's competitiveness in world markets. Conversion factors can be determined by using more refined approaches in order to take into account traded and non-traded goods and externalities associated with the project, but the main objective is always competitiveness in world markets. At a second level of social CBA, distributional weights can be introduced to account for intergenerational distribution, and the value of investment in terms of consumption can be introduced to capture issues related to insufficient savings for development.

Thus assume that we undertake a project in renewable energy which involves increasing output by $\Delta Y(t)$. Let $p_r\,(t)$ be the domestic price associated with increasing the gross investment in renewable energy by $\Delta r\,(t)$ and let all the benefits related to output be in terms of changing consumption by $\Delta C\,(t)$ and consumption be the numeraire. Then the traditional cost benefit rule would be to accept the project if

$$\Delta B = CF_c \Delta C\,(t) - CF_R p_r \Delta r\,(t) \geq 0, \tag{12}$$

where CF_c, CF_R are the conversion factors for consumption and renewables. If the change in output was distributed between consumption and investment as $\Delta\hat{C}$, $\Delta\hat{I}$ and furthermore the change in consumption is distributed between two income groups $\Delta\hat{C}_1$ and $\Delta\hat{C}_2$, then the cost benefit rule would be

$$\Delta \hat{B} = CF_c \left[\left[w_1 \Delta \hat{C}_1 (t) + w_2 \Delta \hat{C}_2 (t) \right] + CF_I \Delta \hat{I} \right] - CF_R p_r \Delta r (t) \geq 0, \quad (13)$$

where $w_1.w_2$ are distributional weights and CF_I measures the value of investment in terms of consumption. Under insufficient savings, $CF_I > 1$.

Rules (11) and (12) do not necessarily lead to the same decision. That is, the project on renewables could be acceptable under the sustainability criterion but not under the traditional CBA criterion and vice versa. The reason is that accounting prices are defined with respect to two different objectives: sustainability for the first case and competitiveness in the world market for the second case.

Suppose that the increase in the capacity of renewables is combined with a reduction in fossil fuels extraction by $\Delta q (t)$. This policy is compatible with a low carbon economy objective since it involves a change in the stock of GHGs by $\Delta E (t)$ due to the reduction in the use of fossil fuels. Let $\Delta \hat{Y} (t)$ be the net change in output, which again is defined in terms of a net change in consumption $\Delta \hat{C} (t)$, then the traditional cost-benefit rule will be to accept the project if

$$\Delta \hat{B} = CF_c \Delta \hat{C} (t) - CF_R p_r \Delta r (t) - CF_X c (X) \Delta q (t) - CF_E \Delta E (t) \geq 0, \quad (14)$$

where $CF_X, CF_E, c(X)$ are the conversion factors for fossil rules and GHGs, and the domestic unit extraction cost for the extracted fossil fuels respectively. Note that since fossil fuels and GHGs are reduced the terms $\Delta q (t)$ and $\Delta E (t)$ are negative.

Following the sustainability criterion the project would be accepted if

$$\Delta G (t) = \Psi_r' \Delta r (t) + \Psi_q' \Delta q (t) \geq 0. \quad (15)$$

This criterion is determined in detail in the Appendix.

Therefore, accepting projects that satisfy the sustainability criterion does not necessarily mean that these projects would have been accepted by traditional CBA. Furthermore acceptance of projects using traditional CBA, even if externalities are accounted for, does not necessarily imply that these projects promote sustainability.

This is a very important dichotomy which should be taken into account when policies are designed. The dichotomy is also important regarding the question related to the project of providing sustainable energy for all (SEFA). Policy makers should make it clear whether a SEFA project or a rural electrification project is evaluated in terms of developmental objectives or sustainability objectives, because the two criteria will not necessarily coincide.

The objectives can be combined to obtain composite decision rules. If the objective is to select projects which are compatible both with sustainability and development then a project will be selected if

$$\Delta G\left(t\right) \geq 0 \text{ and } \Delta B\left(t\right) \geq 0. \tag{16}$$

If the objective is to select projects which combine both targets, then a project will be selected if

$$\lambda \Delta G\left(t\right) + \left(1-\lambda\right) \Delta B\left(t\right) \geq 0 \ , \ 0 < \lambda < 1, \tag{17}$$

where λ reflects the decision maker preferences with respect to sustainability or development.

Different combinations can also be constructed. If the objective is sustainability with an increase in human capital, then the selection rule will be:

$$\Delta G\left(t\right) \geq 0 \text{ and } \Delta h\left(t\right) > 0. \tag{18}$$

If the objective is sustainability and GDP growth, then the selection rule will be:

$$\Delta G\left(t\right) \geq 0 \text{ and } \Delta Y\left(t\right) > 0. \tag{19}$$

In rules (18) and (19) the sustainability criterion ensures that the benefits and the costs of the project are properly valued and the specific criterion ensures that the specific objective is also satisfied.

5 Sustainability, Green Economy and Green Growth

A green economy can be thought of as one which is low carbon, resource efficient and socially inclusive. According to UNEP a green economy results in improved human wellbeing and social equity, while significantly reducing environmental risks and ecological scarcities. In a green economy, growth in income and employment should be driven by public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services.

From the premise that a green economy results in improved human well-being, a connection can be established between green economy and sustainability. The requirements of reduction of environmental risks and ecological scarcities, on the other hand, although they seem to be desirable properties of a sustainability path are not precisely defined.

Thus the concept of a "green economy" is not a substitute for a sustainable economy, but it can be argued that a green economy could lead to a sustainable economy since it will promote resource savings and ecosystem health which are important elements of an economy's productive base. However the test of whether activities related to developing a green economy promote sustainability is that comprehensive investment does not decline under policies supporting a green economy.

Public policies towards a green economy should include:

- Development of renewable sources of energy sources and low-carbon production processes
- Investments in energy-efficient infrastructure
- The introduction of efficient environmental policies mainly in the form of market-based instruments
- Support for R&D spending on green technologies
- Restoration and conservation of ecosystems
- Energy conservation

A procedure that can help decision makers evaluate whether an economy is moving towards a green economy is the so-called greening of the national accounts and the move from GDP to green net domestic product or green NDP. The processes which are based on adjusting the GDP measure can be summarized below:

Table 1: Greening the national accounts from gross domestic product (GDP) to green net domestic product

GDP
LESS capital consumption (produced capital)
= Net Domestic Product (NDP)
LESS consumption of natural capital which includes:
Reduction in the value of stocks of exhaustible
resources (energy resources and minerals)
LESS Losses of ecosystem services
= Adjusted NDP
PLUS nonmarket benefit flows for ecosystem services
= Environmentally adjusted NDP
LESS Health damages due to environmental pollution
= Green NDP

It should be noted that the process for obtaining the green NDP has similarities with the process of obtaining comprehensive investment since it values changes in the stock of assets beyond changes in produced capital. The extent to which the two approaches converge, in the sense of providing similar information about the sustainability of the economy, depends on the number of assets valued during the green NDP adjustment and the prices used for the valuation of changes in the assets.

Green growth is another concept that becomes central in discussions about sustainability and environmental protection. In broad terms green growth can be defined as growth that does not violate the environmental sustainability constraint or, to put it differently, as economic growth under which natural assets continue to provide the resources and environmental services on which human wellbeing relies.

In terms of the analysis and criteria developed above, green growth requires that

$$\Delta Y(t) > 0 \text{ and } G^E(t) > 0.$$

The first requirement ensures conventional growth in terms of GDP, while the second one ensures environmental sustainability at time t since comprehensive investment related to the environment is positive. A small investment project will promote green growth if it increases both output and environmental comprehensive investment.

6 Concluding Remarks

Sustainable development, environmental sustainability, green economies and green growth are issues which are of great importance for both the research and the policy ajenda at global national and local scales. In a recent paper, Xepapadeas and Stefan (2014) indicate that some central issues in research and policy design include population growth in the less developed regions of the world; the evolution of GDP per capita and poverty metrics, life expectancy, child mortality, and literacy rates in the lower income and lower middle income countries; climate change and emissions of carbon dioxide; biodiversity loss and loss; and the emergence of tipping points of global importance related to renewable resources and ecosystem preservation.

It is clear that these issues relate to sustainability and development and that the design of efficient policies to successfully address them represent major challenges of contemporary societies. In the present paper we tried to clearly define the concepts of sustainability and to provide a conceptual framework for developing sustainability-founded cost benefit rules. From the discussion it becomes clear that a certain policy cannot necessarily satisfy simultaneously all the issues in question, that is, sustainable development, environmental sustainability, the development of green economies, and the attainment of development or green growth. Although sustainable development seems to be an encompassing concept, it is not at all clear that the other concepts are subsets of sustainable development. This is important for decision makers because it suggests using more than one criterion depending on the combination of the objectives to be pursued. The cost benefit rules discussed here could provide a basis for a clear distinction among objectives and for project selection mechanisms that promote single or multiple objectives.

7 Appendix

7.1 The Economy

The model economy is described below.

Production function:

$$Y(t) = F(K(t), q(t), r(t), u(t)h(t)N(t), s(t), t) \tag{20}$$

Physical (produced) capital accumulation:

$$\dot{K}(t) = Y(t) - C(t) - c(X(t))q(t) - p_r(t)r(t) - p_\alpha(t)\alpha(t) - \tag{21}$$
$$p_S(t)i(t) - p_{c^s}(t)c^s(t) - \delta K(t) \ , \ K(0) = K_0 > 0$$

Fossil fuel depletion:

$$\dot{X}(t) = -q(t) \ , \ X(0) = X_0 > 0 \tag{22}$$

Accumulation of capacity in renewables:

$$\dot{R}(t) = r(t) - \theta R(t) \ , \ R(0) = R_0 \geq 0 \tag{23}$$

Accumulation of GHGs:

$$\dot{E}(t) = [1 - \psi(C^s(t))]q(t) - \gamma E(t) \ , \ E(0) = E_0 > 0 \tag{24}$$

Human capital accumulation:

$$\dot{h}(t) = h^\xi(t)[1 - u(t)] \ , \ h(0) = h_0 > 0 \tag{25}$$

Accumulation of CCS capacity:

$$\dot{C}^s(t) = c^s(t) - \zeta C^s(t) \ , \ C^s(0) = C_0^s \geq 0 \tag{26}$$

Accumulation of adaptive capacity:

$$\dot{A}(t) = \alpha(t) - \beta A(t) \ , \ A(0) = A_0 \geq 0 \tag{27}$$

Ecosystem evolution

$$\dot{S}(t) = g(S(t)) - s(t) - \psi(E(t)) + \upsilon(i(t)) \ , \ S(0) = S_0 > 0 \tag{28}$$

Social welfare at time t:

$$W(t) = U(C(t)) - [1 - \phi(A(t))] D(E(t)) \tag{29}$$

Intergenerational wellbeing:

$$V(t) = \int_t^\infty e^{-\rho(\tau - t)} [U(C(t)) - [1 - \phi(A(t))] D(E(t))] \, d\tau \tag{30}$$

Notation

Assets: K: produced capital stock, X: stock of fossil fuels, R: stock of renewables, h:human capital, S: ecosystems, E: stock of GHGs, A: adaptation capacity, C^s: CCS capacity

Instruments: C: consumption, q: fossil fuel extraction, $1-u$: investment in human capital, s: flow of ecosystem services used in production, α: gross investment in adaptation capacity, c^s: gross investment in CCS capacity, i: gross investment in ecosystem restoration

Functional dependencies: $U(C(t))$: utility function, $D(E(t))$: damage function due to GHGs and climate change, $\phi(A(t))$: damage reduction due to adaptation capacity, $c(X(t))$: stock dependent unit extraction costs for fossil fuels, $g(S(t))$: ecosystem regeneration function, $\psi(E(t))$: damages to ecosystems due to GHGs and climate change, $\upsilon(i(t))$: ecosystem restoration through restoration investment.

Exogenously determined variables and parameters: $\rho > 0$: social discount rate, $\delta, \gamma, \zeta, \beta$: exponential depreciation rates of assets, $p_r(t), p_\alpha(t), p_S(t), p_{c^s}(t)$: paths of prices for investments in renewables, adaptation, ecosystem restoration, CCS.

7.2 Accounting Prices and Sustainability Criteria

Since the economy is not optimizing, that is instruments are not chosen in order to maximize intergenerational wellbeing, it is natural to assume that instruments are chosen by some arbitrary policy function or feedback rule in terms of assets. For example if we assume that individuals do not optimize savings but they save a fixed share of output, then $C = (1 - mps)Y$, where *mps* is marginal propensity to save. Let

$$\Omega = (K, X, R, h, S, E, A, C^s) \tag{31}$$

denote the vector of assets. Choosing instruments by following feedback rules implies that instruments are defined as

$$M = f_M(\Omega) \ , \ M = (C, q, r, u, \alpha, c^s, i) \tag{32}$$

where not all assets are necessarily involved in the policy function. Substituting the instruments with the policy functions into the dynamical system (21)-(28), we obtain a dynamical systems in terms of assets only. The system will be a nonlinear system of the general form

$$\begin{aligned} \dot{\Omega}(t) &= Z_\Omega(\Omega(t)) \ , \ \Omega = (K, X, R, h, S, E, A, C^s) \\ \dot{\Omega} &= \left(\dot{K}, \dot{X}, \dot{R}, \dot{h}, \dot{S}, \dot{E}, \dot{A}, \dot{C^s}\right). \end{aligned} \tag{33}$$

Assuming that the functions of the dynamic system satisfy appropriate assumptions the system has a solution which can be obtained numerically, whch will determine the paths of the assets as functions of time and initial conditions. So considering an initial state $\Omega(t) = \Omega_t$ at t, the solution of the dynamic system will determine paths

$$\Omega(\tau) = \varphi_\Omega(\Omega_t; \tau) \ , \tau \geq t. \tag{34}$$

Substituting these paths into (29) and (30) we obtain intergenerational wellbeing at t as a function of the assets at t and the entire future paths for the evolution of assets under the given policy functions as

$$\begin{aligned} V(t) &= \int_t^\infty e^{-\rho(\tau - t)} \{U(C(f_M(\Omega_t; \tau))) - \\ &\quad [1 - \phi(\varphi_A(A_t; \tau))] D(\varphi_E(E_t; \tau))\} d\tau \text{ or} \qquad (35) \\ V(t) &= V(K(t), X(t), R(t), h(t), S(t), E(t), A(t), C^s(t), t) . \qquad (36) \end{aligned}$$

The economy is on a sustainable path if

$$\begin{aligned}
\frac{dV(t)}{dt} &\geq 0 \text{ or} \qquad (37)\\
\frac{dV(t)}{dt} &= \sum_{\Omega} \frac{\partial V(t)}{\partial \Omega(t)} \frac{d\Omega(t)}{dt} + \frac{\partial V(t)}{\partial t} \geq 0\\
\Omega &= (K, X, R, h, S, E, A, C^s)\\
\dot{\Omega} &= \left(\dot{K}, \dot{X}, \dot{R}, \dot{h}, \dot{S}, \dot{E}, \dot{A}, \dot{C}^s\right)
\end{aligned}$$

which is criterion (2). Accounting prices are $\frac{\partial V(t)}{\partial \Omega(t)}$ and can be obtained by numerical integration of (35). Then comprehensive investment is obtained as

$$G(t) = \sum_{\Omega} \frac{\partial V(t)}{\partial \Omega(t)} \frac{d\Omega(t)}{dt} + \frac{\partial V(t)}{\partial t}. \qquad (38)$$

7.3 Sustainability cost-benefit rules

Consider the small investment in CCS described in section 3.2., with everything else constant. The change in comprehensive investment will be

$$dG(t) = \left[-\frac{\partial V(t)}{\partial K(t)} p_{c^s}(t) + \frac{\partial V(t)}{\partial C^s(t)}\right] dc^s(t) \qquad (39)$$

and the small investment will be acceptable if $dG(t) > 0$. The costs and benefits from the small investment in CCS realized through the impacts on the assets are captured by the accounting prices $\frac{\partial V(t)}{\partial K(t)}$ and $\frac{\partial V(t)}{\partial C^s(t)}$.

Consider the small investment in renewables $dr > 0$ with a small reduction in fossil fuel extraction $dq < 0$. The cost-benefit rule will suggest undertaking the investment on sustainability grounds if:

$$\begin{aligned}
dG(t) = & \left\{\frac{\partial V(t)}{\partial K(t)} \left[\frac{\partial F}{\partial q} - c(X)\right] - \frac{\partial V(t)}{\partial X(t)} + \right. \qquad (40)\\
& \left. \frac{\partial V(t)}{\partial E(t)} \left[1 - \psi(C^s(t))\right] dq \right\} + \\
& \left\{\frac{\partial V(t)}{\partial K(t)} \left[\frac{\partial F}{\partial r} - p_r\right] + \frac{\partial V(t)}{\partial R(t)}\right\} dr > 0.
\end{aligned}$$

The first line in (40) describes the impacts on intergenerational wellbeing from reducing fossil fuel which are realized through capital formation $\frac{\partial V(t)}{\partial K(t)}$, resource depletability $\frac{\partial V(t)}{\partial X(t)}$ and impact on climate change $\frac{\partial V(t)}{\partial E(t)} \left[1 - \psi(C^s(t))\right].$

The second line describes the impacts on intergenerational wellbeing from increasing renewables which are realized through capital formation $\frac{\partial V(t)}{\partial K(t)}$, and increased renewables capacity $\frac{\partial V(t)}{\partial X(t)}$.

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