8 Sustainable Development: Controversies and Theoretical Results in Economics

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Abstract

This chapter presents the economic conditions for achieving sustainable development and the mechanism by which rational people choose an anti-sustainable path. These are theoretical results derived from the standard economic model. However, the model has faced controversy regarding the concept of sustainable development. This chapter introduces these controversies. By doing so, the implications and limitations of the theoretical results can be well-understood. One controversy concerns what should be sustained in sustainable development, and the other intergenerational equity. For illustration, this chapter often refers to the climate change issue, which raised and fired these controversies. Since the topic is sustainable development, this chapter relates to Sustainable Development Goals as a whole, and it contributes to SDGs 8 (economic growth) and 13 (climate action), among others.

Keywords

Sustainable development · Limits to growth · Tragedy of the commons · Intergenerational equity · Discounted utilitarian approach

8.1 Introduction

Sustainable development is a central social value worldwide that compels us to think of the environment and our far-future descendants. As an introduction to the economics of sustainable development, this chapter presents theoretical results in economics regarding the conditions for achieving sustainable development. Conversely, however, the conditions also reveal the limiting factors that prevent society from achieving sustainable development. Furthermore, the chapter reveals the mechanism by which rational people willingly choose an anti-sustainable path, a situation known as the "tragedy of the commons" (Hardin 1968). These theoretical results contribute to promoting "sustained, inclusive, and sustainable economic growth" in SDG 8 by helping to design a sustainable society and preventing policies that conflict with sustainable development.

Sustainable development has faced several controversies, as is common with important value concepts, such as liberty and human rights. In economics, the focus of the argument is the validity of standard economic models for

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studying sustainable development. Since the theoretical results in this chapter are derived from standard economic models, it is crucial to understand the controversies. By doing so, the implications and limitations of the theoretical results may be well-clarified.

This chapter begins with the controversies in economics surrounding sustainable development. One controversy is concerned with what should be sustained. Most economists believe that well-being should be sustained, a view called weak sustainability. Advocates of strong sustainability assert that the sustainability of natural capital should be considered in addition to well-being. Another controversy concerns intergenerational equity: the problem of how much we should sacrifice for the sake of the well-being of future generations. There are two dominant approaches to address this question: utilitarian and egalitarian. Moreover, there is controversy within the utilitarian approach over whether to discount future generations' well-being or not. The answer to this crucially affects the well-being of future generations.

Standard economic models are based on the concept of weak sustainability and take a discounted utilitarian view to evaluate future generations' well-being. At first glance, these concepts may be either unrealistic or ethically unacceptable. In fact, there have been disputes over them, even among economists. However, these alternatives are not without their own problems.

Climate change has been a central concern in economic research on sustainable development and has led to the aforementioned controversies.[1] The present chapter addresses this issue and partly covers the economics of climate change that contribute to SDG 13: Climate Action.

[1] Each controversy has a long history: The argument on discounting future generations' well-being was raised by Ramsey (1928). The egalitarian approach originated with Rawls's *Theory of Justice* (Rawls 1971). Finally, the choice of strong or weak sustainability has become an argument since the publication of *Our Common Future* (WCED 1987).

8.2 Controversies Around Sustainable Development in Economics

8.2.1 Background and Outline

The notion of sustainable development was first popularized by the International Union for Conservation of Nature and Natural Resources (IUCN) in its *World Conservation Strategy* (IUCN 1980). The report stressed the conservation of the ecosystem and sustainable use of living resources. The World Commission of Environment and Development (WCED), established by the United Nations in 1983 to formulate a global agenda to promote international cooperation toward sustainable development, broadened this notion by stressing the well-being of future generations. In the final report, *Our Common Future*, known as the Brundtland report,[2] the Commission defines sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987, Chap. IV, para. 27). This definition was adopted at the Earth Summit,[3] the largest United Nations conference in the twentieth century, and this notion has spread rapidly.

Among the definitions of sustainable development,[4] the definition by the WCED cited above is the most prevalent. However, it contains two sources of disagreement that have caused controversy.

One source of disagreement is the role of environmental conservation in sustainable development. Today, environmental conservation is recognized, together with poverty

[2] Gro Harlem Brundtland was the chair of WCED, who also served as Prime Minister of Norway. Before the appointment, she was a member of the Independent Commission on Disarmament and Security, established by the United Nations to discuss nuclear disarmament.

[3] The Earth Summit proclaimed, "Human beings are at the center of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature" (United Nations 1992. The Rio Declaration, Principle 1).

[4] Several definitions of sustainable development are listed in the Appendix of Pearce et al. (1989).

eradication and changing consumption and production patterns, as one of the three "overarching objectives of and essential requirements for sustainable development" (United Nations 2002, Johannesburg Declaration on Sustainable Development, para. 11). However, this notion was initially devised to promote international cooperation to prevent global environmental destruction such as biodiversity loss and climate change. This difference is the source of controversy between strong and weak sustainability.

While the Brundtland report emphasizes the well-being of future generations, the definition provides few substantive ideas on how much the present generation should care for future generations. This is another source of controversy. Nordhaus (1994) criticized this definition, as it posits only Pareto efficiency, whereby something is socially desirable if one becomes better off without anyone becoming worse off, as criterial. Replacing "individual" with "generation" makes this definition of sustainable development precisely the same as that used by the WCED.

If later generations are born worse off, this cannot be considered sustainable development, although it might be Pareto efficient. This is because Pareto efficiency is defined as the condition under which no further improvement is possible without eroding the quality of life of some individuals. Therefore, if one generation cannot be better off without eroding the quality of life of another generation, it would be Pareto efficient. This indicates that the notion of sustainable development must include the idea of intergenerational equity.

Efficiency and equity are independent value concepts. As there are many efficient states, it is natural to seek an efficient state that satisfies equity. However, economists almost always consider only efficiency. The fundamental reason for this is the conceptual difficulty in defining equity. A rigorous definition of equity requires welfare judgment in a situation where one feels happy and the other feels sad in a coherent way. To judge whether it is socially good or not, one must weigh these two utilities, but how can we measure one's happiness and the other's sadness? The problem of the "interpersonal comparison of utility" has not been satisfactorily solved.[5] However, when considering sustainable development, we cannot avoid addressing the issue of intergenerational equity. The dilemma of the necessity of addressing the equity problem and the difficulty in defining it is the source of controversy.

Traditionally, economists have adopted a utilitarian approach that considers the sum of well-being over generations as the social welfare to be maximized following the slogan of utilitarianism: the greatest happiness for the greatest number.[6] This does not distinguish between the well-being of present and future generations; therefore, intergenerational equity is treated indirectly at most. Therefore, alternative approaches have been proposed and investigated. The most prominent is an egalitarian approach that distinguishes the least advantaged as entitled to become better off. However, this approach itself is not immune to criticism, and none of these approaches has displaced the utilitarian approach in economics.

Even within the utilitarian approach, there has been controversy for almost a century that has intensified with the emergence of the climate change issue: Whether it is justified to use the discounting formula to aggregate the well-being of generations as if it were cash flows. Discounting is contrary to egalitarianism.[7] Thus, the undiscounted utilitarian approach is morally superior. However, there are difficulties in practice, as discussed in the next section. This partly explains the dominance of the discounted utilitarian approach in economics.

In the remainder of this section, we examine these controversies. These points, as outlined in

[5] Binmore (2005) has tackled this problem.

[6] The reader may wonder why well-being can be treated as a number and how a single number can represent the well-being of a generation. These are hard questions involving the problems of the cardinality of utility and the interpersonal comparison of utility. Nevertheless, for pragmatic reasons, economists accept these assumptions in most cases. The same holds true in moral philosophy (see Hirose 2015).

[7] The standard utilitarian adds up the well-beings with equal weights and thus can be seen as kind of egalitarian.

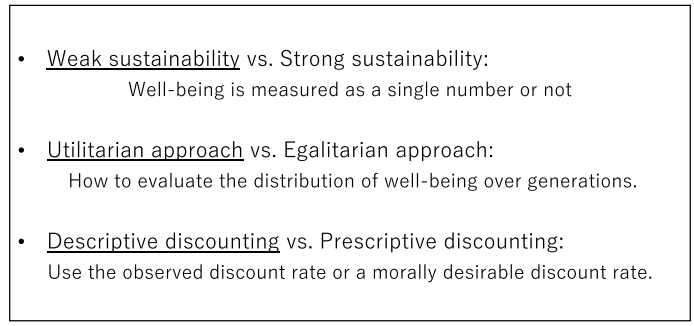

Fig. 8.1 Controversies in economics around sustainable development. *Note* A standard economic model takes the underlined positions

Fig. 8.1, have a nested structure (see the items in the figure from the bottom). First, the choice of discount rates is premised on a utilitarian approach; that is, social welfare (an index of social desirability) is expressed as the sum of the well-being of all generations. Second, the choice between utilitarian and egalitarian approaches is premised on weak sustainability.

8.2.2 Weak Sustainability and Strong Sustainability

Since 1990, the world's forests have decreased by 177 million hectares, which amounts to a 4% loss, larger than China's forested land (134 million hectares; Food and Agriculture Organization 2020). However, the world's human development index has increased consistently from 0.601 in 1990 to 0.737 in 2019 (United Nations Development Programme 2020). The index is calculated based on life expectancy, education, and per capita income. This trend applies to countries at all stages of development.

Confronted by this remarkable gap between the two components of sustainable development, how does one evaluate whether society as whole is on a track to sustainable development? Weak sustainability considers that synthesizing both is possible, with a single number representing the well-being of a generation. The logic is as follows. When a forest is converted to agricultural land, we lose the associated ecosystem services and forest products but obtain food, and this loss may be compensated by the gain, if sufficient. If this relationship, called *substitutability*, holds for all goods and services, then any change results in a change in utility,[8] which is the single number used to evaluate well-being.

The concept of strong sustainability denies this view. There are elements of nature that are essential to life and are not substituted. Greenhouse gases in the air and honeybees as pollinators are examples. They are referred to as *critical natural capital* (Ekins et al. 2003). Irreversibility and threshold also characterize critical natural capital. Once these elements degrade and fall into the critical zone, their restoration is impossible or very difficult, and society suffers fatal damage due to the non-substitutability of these natural elements.

As an indicator of strong sustainability, Ekins et al. (2003) propose the gap between the sustainability standard for critical natural capital and the current situation, terming it as an "S-GAP." The sustainability standard is also called the safe minimum standard for conservation (SMS; Ciriacy-Wantrup 1952).[9] As the number of S-GAPs is the same as the number of critical natural capital stocks, strong sustainability has multiple indicators.

[8] For simplicity, this chapter uses "utility" synonymously with "well-being." Utility is clearly defined in economics: It is the numerical representation of individual preference. By contrast, the definition of well-being is controversial, especially in discussions on equity. See Hirose (2015, pp. 2–3) for a careful discussion and neat treatment and Asheim (2010, p. 201), who gives clear and thoughtful definitions to these terms in the context of intergenerational equity.

[9] The minimum vital population in ecology is an example of SMS. SMS can be not physical but economic such that, although a natural capital is degraded but is still restorable, an economic rationale suggests its unsustainable use. See Clark (1971) and Akao et al. (2011).

To illustrate these two concepts of sustainability, consider the issue of climate change. Policymakers often discuss the carbon budget, which is the total amount of carbon emissions that can be emitted for temperatures to stay below a global target, such as the 2 °C target (United Nations Environment Programme 2020). Minimum-cost emission paths to achieve the target calculated using an integrated assessment model (IAM) have been discussed based on strong sustainability; a climate with a livable temperature is a form of critical natural capital. The world target and carbon budget correspond to the SMS and S-GAP, respectively.

An IAM has also been used to derive an optimal emission path that maximizes social welfare. The Nordhaus dynamic integrated climate economic (DICE) model is a prominent model that expresses the well-being of each generation as a single number—utility.[10] Therefore, it is based on weak sustainability. As shown in Fig. 5.6 in Nordhaus (2008), there is a serious disconnect between the economic-optimal path and the minimum-cost path for achieving the 2 °C target. If the optimal path is taken, the increase in the global average temperature at the end of this century will far exceed 2 °C.

Weak sustainability pays little attention to the non-substitutability and irreversibility of critical natural capital. Therefore, the policy implications may tend to be over-optimistic. However, knowledge of critical natural capital stock is still limited. Moreover, even if we possess knowledge in this regard, there is considerable uncertainty about the threshold in general, as in the case of climate change. Furthermore, capital's non-substitutability and irreversibility do not emerge until the capital stock reaches the threshold, and we know little about what happens at the tipping point. Given these uncertainties, stressing the characteristics of critical natural capital may tend to be too pessimistic. In other words, strong sustainability may be too cautious.[11] Therefore, these two concepts of sustainability can lead to a debate on environmental policy: Environmental regulation may be seen as too lax by the supporters of strong sustainability and too strict by the supporters of weak sustainability.

While the policy implications can differ between weak and strong sustainability, there is no difference in economic modeling. From both views, a desirable state is formulated as a solution to an optimization problem with constraints. Recall previous examples of weak and strong sustainability. As an example of a weak sustainability approach, the DICE model maximizes the aggregate sum of utility over generations with constraints on production possibility, including emission abatement costs and the global climate system. An efficient path satisfying the 2 °C target, as an example that follows strong sustainability, is a solution to a cost minimization problem with the constraint that global average temperatures must be lower than the target. Maximization and minimization are interchangeable; maximizing the good is equivalent to minimizing the bad. Therefore, formally, the debate between the two views concerns the constraints that should be imposed on the problem in question. In contrast, the following two subsections focus on what is optimized.

8.2.3 Utilitarian and Egalitarian Approaches for Intergenerational Equity

In 1972, the first world conference on environmental issues, the United Nations Conference on Human Environment, was held. It cautioned that if the human capability and power are "[w]rongly or heedlessly applied, the same power can do incalculable harm to human beings and the

[10] William Nordhaus was awarded the Nobel Prize in Economics in 2018 for his pioneering and influential works on the economics of climate change.

[11] This leads to how cautious we should be about future uncertain events, which is the central question around the validity of the *precautionary principle*, another essential but controversial concept regarding environmental issues. See Sunstein (2005).

human environment" (Declaration of the Nations Conference on the Human Environment, para. 3).

Before the conference, the Club of Rome report, *The Limits to Growth* (Meadows et al. 1972), was published. The report warned about the sustainability of modern civilization, which depends heavily on nonrenewable fossil resources. The share of fossil fuels in global energy consumption was 94% in 1972.[12] People realized that prosperity was jeopardized due to several problems that emerged alongside steady economic growth, such as environmental pollution, resource exhaustion, and the population explosion. Economists began intensive studies of egalitarian approaches.

One of the reasons is the description of the economy in *The Limits to Growth*, which relies heavily on a nonrenewable resource. A traditional utilitarian approach suggests that an anti-sustainable development path is socially optimal for such an economy. In other words, well-being decreases over time along the optimal path.

An egalitarian approach can help avoid this repugnant result. It is based on the Rawls' Difference Principle, which treats it as distributivity-just to make the least advantaged in society better off (Rawls 1971, Sect. 13). This is also called the maximum approach because maximizing the minimum level of well-being is socially optimal.

With this approach, an optimal path entails the same utility over generations; this is called an egalitarian path.[13] Therefore, a declining utility path is never chosen. However, a problem arises when an increasing utility path becomes feasible. Even in this case, a constant path is optimal. When the utilitarian optimal path increases, the egalitarian approach recommends that the present generation consumes more and pollute more than the utilitarian optimal path; otherwise, the present generation stays in the least advantaged position. This is another undesired result. The attractiveness of this approach over the utilitarian approach is reversed.

The overall appeal of these approaches depends on one's perspective on future development. The egalitarian approach would be supported by people who believe that modern society is on a doomsday trajectory; that is, future generations can be at most as well off as the present generation and, therefore, are likely to be worse off. However, people who believe that sustainable development is achievable would consider that well-being can increase in the future. Otherwise, sustainable development is infeasible and its achievement is logically impossible. From this perspective, the egalitarian approach is less attractive because it leads to the following paradoxical suggestion[14]: Although we can make our children happier than us, it is unfair to us, and the idea of making them better should be dismissed. In contrast, the utilitarian approach suggests that making them happier than us is always good if their gain is more than our loss.

The discussion of sustainable development, as mentioned above, is based on the premise that a sustained improvement in well-being is feasible. However, the social justification of a sustainable development path and the desire of present generation to engage in such development remains unclear. Unfortunately, the egalitarian approach fails to answer the requisite social justification. Hence, this chapter considers these questions of justification and desire within the framework of utilitarianism.

8.2.4 Arguments About Discounted Utilitarianism

Even within the utilitarian approach, there is long-standing controversy as to whether we should discount future generations' well-being.

[12] It remains high: 83% in 2020. (BP Statistical Review of World Energy).

[13] An egalitarian path may be infeasible in an economy heavily relying on a nonrenewable resource. The feasibility depends on whether an essential nonrenewable resource can be substituted by a manufactured product (Solow 1974; Cass and Mitra 1991). Recall the discussion of strong/weak sustainability. Again, the essentiality and substitutability of a natural resource matter.

[14] Rawls (1971) noticed this problem and showed reluctance to applying the maximin approach to intergenerational equity.

This argument has flared because of climate change.

The Stern Review (Stern 2007) is an economic analysis of climate change presented by the British government in 2006. It is prominent not only for its influence, but also for its radical policy recommendation: Urgent, sharp, and immediate reductions in greenhouse gas emissions are needed. The optimal carbon emission reduction is much larger than the other economic analyses. Furthermore, it is larger than the minimum-cost path for achieving the 2 °C target (see Nordhaus 2008, Fig. 5.6).

The model used in the Stern Review is essentially the same as the other IAMs, but the parameter choice is different. In particular, the choice of the discount rate is crucial to the radical recommendation. Therefore, the Stern Review rekindled a long-running controversy over the appropriate discount rate for social decision making. Before introducing the argument, the discount rate and discounted utilitarian approach are briefly explained.

A discount rate transforms a future value to its present value to enable the comparison and summation of values at different points in time. For example, letting r be the discount rate, the present value of 1000 dollars 10 years from now is calculated as $1000/(1+r)^{10}$ dollars. The word "discount" comes from the fact that the present value is less than 1000 dollars if received now, so long as r is positive.

A term similar to the discount rate is the *discount factor*, $d = 1/(1+r)$. With the discount factor, the aforementioned present value is written as $d^{10} \times 1000$. Note that if $r > 0$, then $0 < d < 1$, and if $r = 0$, then $d = 1$.

To illustrate the summation of the present values, assume that we will receive 1000 dollars every year for ten years from today (ten times). The total present value is then calculated as $1000 + 1000/(1+r) + \cdots + 1000/(1+r)^9$. With the discount factor, it is written as $1000 + d \times 1000 + \cdots + d^9 \times 1000$.

Applying this formula, a standard economic model formulates an intertemporal social welfare function as

$$W(u_1, u_2, \ldots) = u_1 + \delta u_2 + \delta^2 u_3 + \cdots, \quad (8.1)$$

where $u_i (i = 1, 2, \ldots)$ is the utility of the i th generation and δ is the discount factor. Let ρ be the discount rate. Subsequently, δ is given by $\delta = 1/(1+\rho)$.[15] The discounted utilitarian approach assumes that $\rho > 0$ (and thus $\delta < 1$), whereas if $\rho = 0$ (and thus $\delta = 1$), the social welfare function follows the (undiscounted) utilitarian approach.[16]

Stern (2007) chose zero discounting ($\rho = 0; \delta = 1$) for the ethical reason that all generations should be treated equally.[17] By contrast, most economists adopt a positive discount rate, although this discounted utilitarian approach has been repeatedly criticized.[18] The most famous and oldest criticism is by Ramsey (1928), a mathematician, philosopher, and economist. Since he first formulated the aforementioned model, it is now called the Ramsey model. In his words, "we do not discount later enjoyments in comparison with earlier ones, a practice which is ethically indefensible and arises merely from the weakness of the imagination." (Ramsey 1928, p. 543).

[15] Note that the notations of the discount rate and the discount factor have been changed because they are used to discount the utility, whereas r and d are used to discount the monetary value. Therefore, they should be distinguished. An intuitive reason for this is simply that happiness and money are different. A fundamental difference is that ρ and δ are part of preference, which constitutes the economy's fundamentals. In contrast, r and d are derived from the fundamentals through a social system of markets and institutions.

[16] The reader may wonder why the model considers the infinite future and if the model can be mathematically well-defined in the undiscounted case. For the answers, see Léonard and Long (1992, pp. 285–287).

[17] In actuality, the Stern Review uses 0.1% as the discount rate. This value reflects "the annual risk of catastrophe eliminating society" (Stern 2007, p. 161). When this kind of risk is incorporated into the model, the discount rate is the sum of the pure rate of time preference, zero in the Stern Review, and the hazard rate. The pure rate of time preference is the parameter representing our impatience.

[18] See Dasgupta (2019), especially Chap. 9, for a comprehensive exposition and in-depth thoughts on this topic.

To indicate the meaning of the "weakness of the imagination," take 1% as an annual discount rate, which is near zero and much lower than usually used in economics. With this discount rate, the current value 10 years from now is discounted by 9.5%, when it is transformed to the present value. The depreciation is not very large. If we consider the current value 30 years from now, the most extended period for a long-term public project, the present value is discounted by 26%. This is still not very large. However, if we consider the current value 100 years from now, the present value is discounted by 61%. In the case of 500 years, the present value is discounted by 99%. If we overlook this unjustly low valuation for distant future generations, we will not escape the accusation of having a weak imagination.[19] It should be noted that 500 years should be incorporated into the timescale of sustainable development.

This example also shows that any small benefit for the present generation can be justified in discounted utilitarianism, regardless of how high the cost is, provided that sufficiently distant future generations incur the cost. For example, assume a project that provides a utility gain of 1 point to the present generation and imposes a 1000-point loss of utility on a future generation. Then, when the discount rate is 1%, if the generation more than 700 years from now suffers from the cost, the project is accepted by a discounted utilitarian because the present value of the 1000-point utility loss is less than 0.95 points, and discounted utilitarian social welfare increases by implementing this project. Chichilnisky (1996) called this property *the dictatorship of the present*.

A discounted utilitarian approach is usually adopted in economic analysis despite these morally unacceptable traits for two reasons. First, we behave impatiently as though we have a positive discount rate. If we use a morally just but unrealistically low discount rate, the associated optimal path over generations would not be optimal in the real world. In the context of the climate change issue, this means that an optimal emission path derived with a zero-discount rate, as in the Stern Review, can be replaced with an alternative path that has the same mitigation effect on the climate with a lower social cost.[20] This problem cannot occur if the discount rate derived from real-world observations is used. This discount rate is adopted in the discounted utilitarian approach. Arrow (1999) views this as a descriptive discount rate, and the zero-discount rate as the prescriptive discount rate.

Second, an optimal path derived with a zero-discount rate seems too radical to implement. We consider the climate change issue. Figure 8.2 illustrates the three *social costs of carbon* (SCC). SCC is defined as the sum of the damages in the future caused by a one-ton current emission of carbon dioxide. Theoretically, to achieve an optimal path, it is necessary to impose a tax per ton of carbon dioxide worldwide of the same amount as the SCC or implement an equivalent policy measure, such as a worldwide emission trading system. The market equilibrium price of the emission permits should be equal to that of the SCC. Both measures are called *carbon pricing* because they price carbon emissions.

Figure 8.2 shows a considerable difference between the SCCs. The DICE2016R is based on a discounted utilitarian, whereas the Stern Review is based on an undiscounted utilitarian. To consider their acceptability, we compared them with actual carbon prices. According to the World Bank (2020, Fig. 2.3), the carbon prices as nominal prices on April 1, 2020, are higher than the Nordhaus SCC in 2020 in six countries, but even the highest price (US\$119/tCO_2e, Sweden's carbon tax) is less than half of Stern's SCC. The report states that approximately half of the covered emissions are priced at less than US \$10/tCO_2e, and the IMF calculates the global average carbon price as only US\$2/tCO_2 (World Bank 2020, pp. 7–8). These figures exemplify the difficulty of implementing an optimal path using an undiscounted model.

Figure 8.2 also shows that the SCC of the 2.5° maximum is similar to that of the Stern

[19] With a 3% discount rate, the discounts are 25% (10 years), 59% (30 years), 94% (100 years), and 99.99996% (500 years).

[20] See Nordhaus (1999) for the illustration.

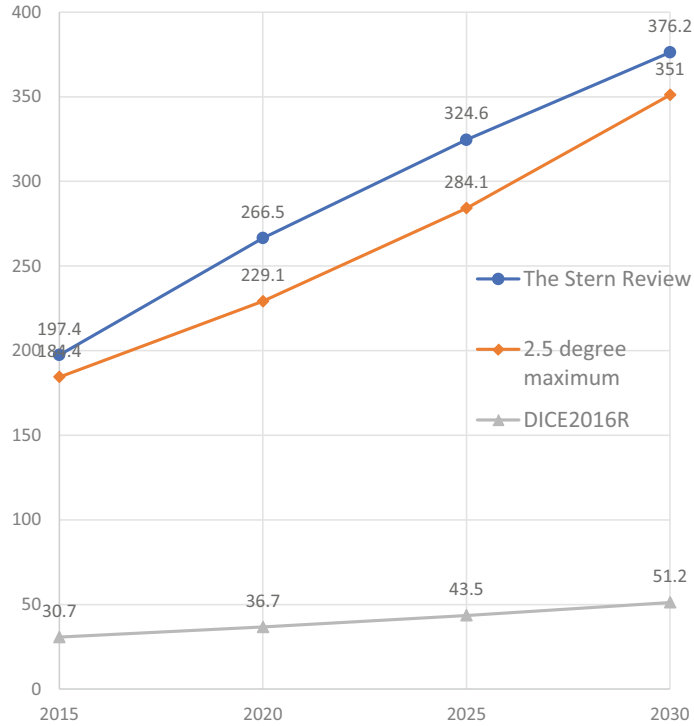

Fig. 8.2 Estimation of the social cost of carbon. *Notes* (1) The SCC is measured in 2010 international US dollars. (2) DICE2016R is calculated along the optimized emission path. (3) The 2.5 °C maximum is calculated along the optimized emission path with constraint. (4) It is expected that without net negative emission technology that has not yet been practically realized, the 2 °C target in the Paris Agreement will inevitably be exceeded. Refer to Ricke et al. (2017) for details. *Source* Nordhaus (2017, Table 1)

Review.[21] This similarity implies that the implementation of carbon prices suggested by the SCC of the Stern Review may be appropriate from the viewpoint of strong sustainability. Hence, we encounter the first controversy between weak and strong sustainability.

Although it is beyond the scope of this chapter, some economists have addressed the justification of high carbon prices in the framework of weak sustainability and discounted utilitarianism, that is, based on standard economics. Gerlaph and Liski (2017) consider non-geometric discounting that may be more plausible to describe our decision making for far-future generations than the standard discounting mentioned. Dietz et al. (2020) reconsider the results obtained from 6 IAMs in economics by updating their climate modules. In these studies, appropriate carbon prices are higher than their reference models. Furthermore, Weitzman (2007) conjectures that explicit incorporation of the possibility of catastrophic risk into economic analysis would be a prospective approach to understanding appropriate carbon prices and solving the discounting argument.

8.3 Economic Conditions for Sustainable Development

8.3.1 Outline

This section presents the conditions for achieving sustainable development within the framework of discounted utilitarianism. As discussed in the

[21] However, they are different in an important respect. While the optimal path by the Stern review is suboptimal in practice, the path induced by the implementation of the SCC of the 2.5° maximum is truly an optimal path under the temperature constraint.

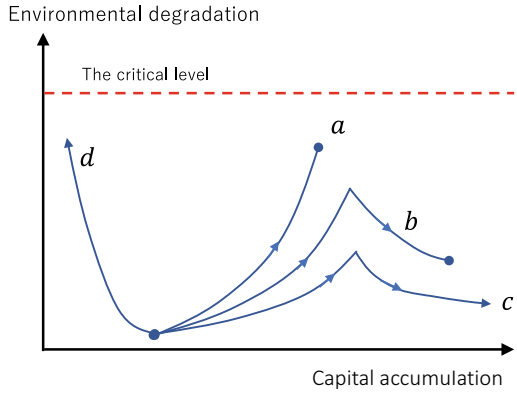

Fig. 8.3 Four paths of development and the environment

previous section, this approach has received moral criticism but has the advantage of reflecting reality better than alternative approaches. In addition, several insightful results follow from using this approach.

Figure 8.3 illustrates four stylized development paths. The horizontal axis represents capital accumulation. A move from left to right indicates economic development. The term "capital" is broadly used to indicate manufactured tangible capital such as machines, plants, and roads; intangible human capital such as knowledge, technology, and the arts; and natural capital such as the climate system, ecosystems, soil, and genetic resources. Capital is a primary source of well-being.

The environment is another primary source of well-being. The vertical axis represents the environmental degradation level. The environment is degraded by, for example, the increase in air and water pollution, destruction of the stratospheric ozone layer, loss of biodiversity, and accumulation of hazardous waste. The horizontal dashed line at the top indicates the critical level of the environment. Once environmental degradation reaches this level, the environment completely loses its regenerative and assimilative capacity, and the economy inevitably suffers fatal damage. These threats include the extinction of renewable natural resources and global warming to a level that releases frozen methane from the oceans into the atmosphere.

The four paths begin from a common initial point. This point indicates a state in the early stage of economic development, where most capital stocks are natural capital and the pollution level is low. Paths A, B, and C represent economic development.

Along Path A, capital increases with a consistent degradation of the environment. Because continuation is a doomsday approach, economic growth must end before the path reaches the critical level of the environment.

In contrast to Path A, Path B has a turning point. After passing the turning point, society enjoys economic growth and environmental improvement. This hump-shaped pattern is known as the *environmental Kuznets curve* (EKC). Grossman and Krueger's (1995) work is one of the earliest EKC studies. Using cross-country data, they showed the existence of the EKC relationship between per capita income and several environmental indices, such as sulfur dioxide emissions and biological oxygen demand. Since their seminal study, intensive empirical studies have been conducted on the existence of the EKC.

Finally, Path C has unlimited economic growth and environmental improvement. Therefore, this may be referred to as a sustainable development path.

All three paths are derived from the maximization problem of the intertemporal social welfare function (1). That is, they are all optimal paths. If Path A is optimal, rational people will willingly take an unsustainable path. If Path B is optimal, they have economic development and environmental conservation; however, there is a limit. If Path C is optimal, they achieve sustainable development. Which path constitutes the optimal path is a crucial question. Section 8.3.2 shows the conditions.

Path D is entirely different from the other paths. Economic decline is accompanied by environmental degradation. Although this worst path can be optimal under certain conditions, suboptimal paths are considered below.[22] In this

[22] This anti-sustainable development path can be optimal if the initial level of capital is lower than the SMS discussed in Sect. 8.2.2 of this chapter. See footnote 9 as well.

case, although Paths A, B, or C are optimal, rational people spontaneously take a suboptimal and anti-sustainable development path. This situation is known as the *tragedy of the commons* (Hardin 1968). "Commons" is a communally farmed land in medieval England, but in Hardin (1968), it is a metaphor for capital that anyone can use freely.

Examples of such capital include high-sea fisheries and the atmosphere as a dumpsite of greenhouse gases. Whales are close to extinction and climate change jeopardizes the well-being of future generations. As such, the tragedy of the commons is ubiquitous. It is also a fact that these issues have been addressed through international conventions: the International Convention for the Regulation of Whaling for the former and the United Nations Framework Convention on Climate Change (UNFCCC) for the latter. The important question is whether these international efforts can remedy the tragedy of the commons. This question is addressed in Sect. 8.3.3, following the exposition of the mechanism by which rational people choose Path D.

8.3.2 Sustainable Development or the Limits to Growth?

This subsection describes the conditions that determine which path (A, B, or C), is socially optimal. To this end, we briefly explain the mechanism of economic development along an optimal path.

If the rate of return on investment measured in terms of utility is higher (lower) than the discount rate, the investment of one additional unit of capital increases (decreases) the intertemporal social welfare (1).[23] In other words, capital accumulates along the optimal path only if its marginal productivity exceeds the discount rate.

This result implies that manufactured physical capital and human capital increase at the early stage of development, whereas natural capital decreases, accompanied by environmental degradation as shown in Paths A, B, and C in Fig. 8.3. Note that natural capital is near physical and ecological equilibrium at this stage. This implies that the marginal productivity is near zero, and thus, is less than the discount rate at the stage.

We now consider the economic mechanism that separates Paths A, B, and C.[24] Along these paths, economic development increases income. As income increases, people consume more goods, and the value of additional consumption decreases relative to the value of services unpurchased in the market, including the quality of the environment. Along an optimal path, this causes an increase in demand for a better environment, and the government reacts by strengthening environmental regulations. Consequently, environmental improvements are accelerated. When the speed of environmental improvement exceeds the speed of environmental degradation at some point in economic development, we have the turning point of Paths B and C. However, if environmental improvement falls behind environmental degradation, Path A is selected as the optimal path.

There are two conditions for society to take Path B or C. First, our preference for tangible and purchasable goods should not be overly greedy. This preference determines the strictness of environmental regulations and thus the speed of environmental improvement. The other condition is that the regeneration and assimilation capacities of nature be sufficiently high to restore the environment. These capacities determine the speed of environmental degradation. That is, the higher the capacities, the slower the environmental degradation. These two conditions work such that an optimal path has a turning point,

[23] The discount rate is the descriptive discount rate (see Sect. 8.2.4 of this chapter). The discounted utilitarian approach assumes that the intertemporal social welfare function introduced in Sect. 8.2.4, which consists of the discount rate and the one-period utility function, can be estimated from the observable data. Moreover, it assumes that the estimated function represents the social preference, that is, the desirability for the society. Arrow et al. (2003, p. 652) urge caution about this view.

[24] The formal exposition of the results can be found in Stokey (1988), Aghion and Howitt (1998, Chap. 5), and Akao and Managi (2007).

after which we have both economic development and environmental improvement.

Whether Path B or Path C is optimal depends on the environmental properties of the growth engine in the economy. The engine is an industrial sector in which the marginal productivity of capital is sufficiently higher than the discount rate to make continuous investment in the industry profitable. Continuous investment enables the industry to grow, which leads to economic growth.

Path C becomes optimal when the economy is equipped with a clean growth engine. The meaning of "clean" is that the economic activities of the growth-engine sector do not negatively affect the environment. Under this condition, the environment is decoupled from economic development. As a result, a path along which society has both unlimited economic development and environmental improvement; that is, Path C can be an optimal path.

If the growth-engine industry is not clean, the industry will eventually cease to grow. To examine this, we consider the effects of environmental regulations on the industry. Environmental regulations are strengthened as the economy grows. As a result, a firm in the industry inputs more resources for environmental measures, sacrificing production and investment. The marginal productivity of capital decreases as environmental regulations become stricter because the return on additional investment is partly used for environmental expenditure. When marginal productivity decreases to the market interest rate, investment becomes unprofitable, and the growth-engine sector ceases to grow. This explains why Path B has limited growth. If the growth engine is clean and unaffected by strengthening environmental regulations, it avoids a reduction in the marginal productivity of capital. Thus, Path C becomes the optimal path.

We have seen that there are three conditions for an optimal path to be a sustainable development path (Path C): (1) less greedy consumers, (2) high resilience of the environment, and (3) a growth-engine sector that is harmless to the environment. The first condition concerns preferences. Therefore, education and culture play an important role in satisfying this need.

The second condition is related to the use of natural capital. For example, if society depends heavily on fossil resources, this condition is not satisfied because the regeneration rate is zero. The same is true for a society in which primary pollutants do not easily decompose naturally. Examples include carbon dioxide and radioactive wastes. Decarbonization and nuclear power phase-out are crucial tasks for avoiding climatic catastrophes and severe radioactive pollution. In addition, the above result indicates that it is necessary to prevent rational people from choosing an anti-sustainable development path.

The third condition implies that leading industries for economic development should use intangible assets, such as knowledge and information as inputs, and output intangible goods, such as knowledge and art. Thus, their activities do not negatively affect the environment. Along a sustainable development path, people in the future will gain utility mainly from intangible goods, and the dematerialization of society will advance.

8.3.3 The Tragedy of the Commons and International Environmental Agreements

This subsection shows how the tragedy of the commons does and does not occur and discusses whether an international environmental agreement can work as a remedy for the tragedy. While the previous subsection considered a socially optimal path, this subsection considers a suboptimal path resulting from collective actions by individually rational people.

Economists distinguish between two types of commons: open-access resources (OARs) and common pool or property resources (CPRs). The difference lies in the number of users of the resource. An OAR is free-entry and has an unspecified number of users, whereas CPR users are fixed. An example of an OAR is a forest that suffers illegal invasion by the landless poor. They come from nowhere, seeking cropland. There are several examples of CPR. For example, several

global environmental issues can be considered problems with CPR. In the negotiations, the people concerned with the problem are represented by fixed countries.

First, we consider an OAR, a distinctive feature of which, owing to its free-entry nature, is that a new resource user continuously enters an OAR as long as there is a positive gain. Therefore, if a user saves resources for future use, the saved resources may be consumed by other users. Users of an OAR behave myopically because saving is meaningless.

In an economic model, myopic behavior is translated into a discount rate with an infinite value. We recall the mechanism of capital accumulation explained in the previous subsection. Marginal productivity is finite and is dominated by an infinite discount rate for any capital stock. Thus, capital stock decreases, accompanied by resource destruction; that is, a society based on an OAR takes Path D in Fig. 8.3.

It still remains unclear whether this anti-sustainable development path is a trajectory to ruin as per Hardin's prediction: "Freedom in a commons brings ruin to all" (Hardin 1968, p. 1244). Dasgupta (1982, p. 13) pointed out that this is not always true. For example, with a classical resource economics model called the Gordon–Schaefer model (Gordon 1954), the equilibrium path of an OAR converges to a positive level of resource stock and ruin is avoided. The mechanism is as follows. In the model, the cost of using one more resource (i.e., the marginal cost of resource use) increases as resources become scarce. There is a positive stock level for the resource, at which point neither further resource use nor new entry is profitable. Thus, resources no longer decrease beyond this stock level.

However, Hardin's dismal prediction may emerge when population growth is combined with the Gordon–Schaefer model. Brander and Taylor (1998) demonstrate this in a theoretical inquiry into the rise and decline of Easter Island. They address the mystery of Easter Island: Why did the civilization of Easter Island collapse, whereas many other Polynesian islands did not? They explained that the difference could be attributed to the regeneration capacity of palm trees, which are critical natural capital on the island. The regeneration capacity of palm trees is remarkably lower on Easter Island than on the other Polynesian islands owing to the unique climatic conditions. With their model, population growth on Easter Island causes resource depletion and famine, leading to war for resource and societal collapse. This occurs in a society that depends heavily on natural resources with low regeneration capacity. Moreover, even if the natural resources had been well-managed and society had taken a socially optimal path, the optimal path might have not been accompanied by environmental improvement, as shown in the previous subsection. The dependence on natural resources with low regeneration capacity threatens sustainable development.

Next, we consider CPR. In contrast to OARs, there are several possibilities for using resources. If other users utilize maximum effort to harvest the resource, the optimal strategy of the user is to follow them. This equilibrium path of resource use leads to the tragedy of the commons. However, another equilibrium path may exist. If other users harvest the resource sustainably, adopting a sustainable harvest strategy can be optimal. This is because when other users adopt a sustainable strategy, a user is not deprived of the resources saved today by the other users. Saving the resource can then make the user better off if the rate of return is higher than his or her discount rate by the same logic of capital accumulation along a socially optimal path mentioned in the previous subsection. Therefore, a sustainable harvest strategy is the best response to the harvest strategies of other users.

This strategic interaction can create various equilibrium paths because the best response depends on other users' strategies. Sorger (1998) illustrates multiple equilibria with a model that he describes as a resource game. He calls the above-mentioned disastrous equilibrium path the most rapid extinction path because the resource becomes extinct at the highest speed. The other paths can be called sustainable equilibrium paths because each of them converges to a positive level of resource stock.

He shows that these equilibrium paths can coexist and that there are uncountably many sustainable equilibrium paths if they exist. However, only the most rapid extinction path exists if the discount rate is high, the number of users is large, or the harvesting ability is high. Although this result is derived from a specific model, it provides important implications on how we can maintain the possibility of taking a sustainable path. For example, it may be necessary to control the use and development of harvesting technology for the sustainable resource use of CPR.

Sorger (1998) also shows that when sustainable equilibrium paths exist, there is an equilibrium path similar to a socially optimal path in resource use when the initial stock is sufficiently close to the socially optimal steady state. This is surprising because rational but non-cooperative people can realize an almost efficient outcome without any rules or institutions. The question, then, is how resource users choose a desirable equilibrium path. One possible answer to this is communication. In theory, they can choose such a path if they communicate before starting resource use.[25] An example in the real world is an international environmental negotiation, in which countries pursue their national profit from environmental agreements. This situation is the tragedy of the commons and is modeled as the resource game of Sorger (1998). As previously mentioned, there are several equilibrium paths. The existence of an approximately optimal path implies that policy coordination can attract interest. It should be noted that coordination, not cooperation, is discussed. Even if cooperation is difficult because of self-interest, countries can agree on policy coordination through negotiations.

For example, the UNFCCC has developed a situation in which all member countries can gain by coordinating their climate policies. As a result, the Paris Agreement was adopted in 2015. Under the agreement, all member countries submitted their climate policies until 2030, called the "Nationally Determined Contributions" (NDCs). However, as is well known, the carbon emission path following NDCs has a large gap with the minimum-cost path to achieve the 2 °C target.[26] Therefore, the United Nations has requested that member countries revise their initial NDCs to a more ambitious plan, and some countries have responded accordingly. This move can be interpreted as a process of selecting a better equilibrium. Whether this approach of the Paris Agreement, known as the pledge and review approach, succeeds in achieving the long-term target, is an essential question for solving the climate change issue and thus for the sustainability of society. Further development of economic theory on CPR would contribute to finding an answer to this question.

8.4 Concluding Remarks

The time horizon for sustainable development covers many generations and centuries. From a long-term perspective, Sustainable Development Goals (SDGs) seek to guide the present generation toward sustainable development. Since there is a trade-off in well-being between the present generation and future generations, we need a value criterion for intergenerational equity to judge a good target and policy. We also need to understand the mechanisms whereby sustainable development is achieved, as well as how an unsustainable path is willingly chosen. This chapter provides theoretical results and discussion of these topics, which potentially relate to all the SDGs, their targets, and the policies to achieve them.

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[25] Note for readers familiar with game theory: The desirable sustainable equilibrium is the payoff dominant equilibrium. While Aumann (1990) doubts the idea that cheap talk leads players to choose the payoff dominant equilibrium, an international environmental negotiation situation may be different from what Aumann (1990) assumes.

[26] See Fig. 2 in UNFCC (2015). As seen by comparing it with Fig. 5.6 in Nordhaus (2008), the NDC path is similar to the optimal path of the DICE model.

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