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# Environmental & Natural Resource Economics

*8th Edition*

2009


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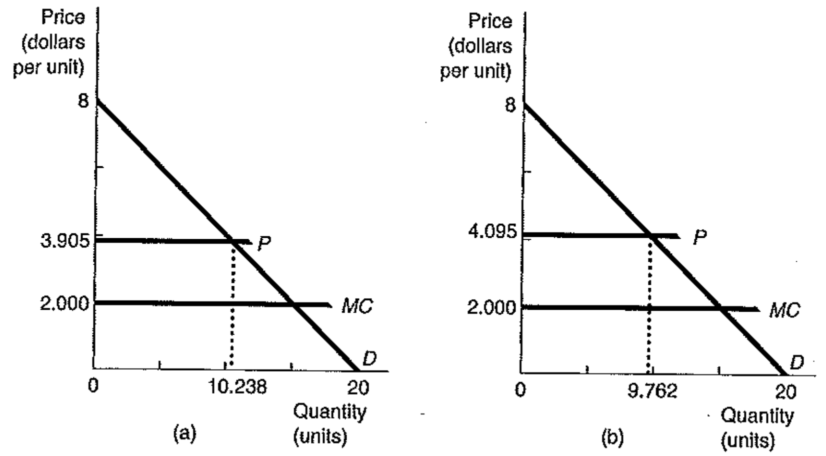
FIGURE 5.3 The Efficient Market Allocation of a Depletable Resource: The Constant-Marginal-Cost Case (a) Period 1 (b) Period 2




the point at which it intersects the horizontal axis. (Can you see why?) The larger the discount rate, the greater the amount of rotation required. The amount allocated to the second period would be necessarily smaller with larger discount rates. The general conclusion, which holds for all models we consider, is that higher discount rates tend to skew resource extraction toward the present because they give the future less weight in balancing the relative value of present and future resource use. The choice of what discount rate to use, then, becomes a very important consideration for decision-makers.

# Defining Intertemporal Fairness

While no generally accepted standards of fairness or justice exist, some have more prominent support than others. One such standard concerns the treatment of future generations. What legacy should earlier generations leave to later ones? This is a particularly difficult issue because, in contrast to other groups for which we may want to ensure fair treatment, future generations cannot articulate their wishes, much less negotiate with current generations ("We'll take your radioactive wastes, if you leave us plentiful supplies of titanium.").

One starting point for intergenerational equity is provided by philosopher John Rawls in his monumental work *A Theory of Justice*. Rawls suggests one way to derive general principles of justice is to place, hypothetically, all people into an original position behind a "veil of ignorance." This veil of ignorance would prevent them from knowing their eventual position in society. Once behind this veil, people would decide on rules to govern the society that they would, after the decision, be forced to inhabit.

In our context this approach would suggest a hypothetical meeting of all members of present and future generations to decide on rules for allocating resources among generations. Because these members are prevented by the veil of ignorance from knowing the generation to which they will belong, they will not be excessively conservationist (lest they turn out to be a member of an earlier generation) or excessively exploitative (lest they become a member of a later generation).

What kind of rule would emerge from such a meeting? One possibility is the sustainability criterion. The *sustainability criterion* suggests that, at a minimum, future generations should be left no worse off than current generations. Allocations that impoverish future generations, in order to enrich current generations, are, according to this criterion, patently unfair.

In essence, the sustainability criterion suggests that earlier generations are at liberty to use resources that would thereby be denied to future generations as long as the well-being of future generations remains just as high as that of all previous generations. On the other hand, diverting resources from future use would violate the sustainability criterion if it reduced the well-being of future generations below the level enjoyed by preceding generations.

One of the implications of this definition of sustainability is that it is possible for the current generation to use resources (even depletable resources) as long as the interests of future generations could be protected. Do our institutions provide adequate protection for future generations? We begin with examining the conditions under which efficient allocations satisfy the sustainability criterion. Are all efficient allocations sustainable?

## Are Efficient Allocations Fair?

In the numerical example we have constructed, it certainly does not appear that the efficient allocation satisfies the sustainable criterion. In the two-period example, more resources are allocated to the first period than to the second. Therefore, net benefits in the second period are lower than in the first. Sustainability does not allow earlier generations to profit at the expense of later generations, and this example certainly appears to be a case where that is happening.

Yet choosing this particular extraction path does not prevent those in the first period from saving some of the net benefits for those in the second period. If the allocation is dynamically efficient, it will always be possible to set aside sufficient net benefits accrued in the first period for those in the second period, so that those in the second period will be at least as well off as they would have been with any other extraction profile.

We can illustrate this point with a numerical example that compares a dynamic efficient allocation with sharing to an allocation where resources are committed equally to each generation. Suppose, for example, you believe that setting aside half (10 units) of the available resources for each period would be a better allocation than the dynamic efficient allocation. The net benefits to each period from this alternative scheme would be $40. Can you see why?

Now let's compare this to an allocation of net benefits that could be achieved with the dynamic efficient allocation. If the dynamic efficient allocation is to satisfy the sustainability criterion, we must be able to show that it can produce an outcome such that each generation would be at least as well off as it would be with the equal allocation. Can that be demonstrated?

In the dynamic efficient allocation, the net benefits to the first period were 40.466, while those for the second period were 39.512.[6] Clearly, if no sharing between the periods took place, this example would violate the sustainability criterion; the second generation is worse off.

But suppose the first generation was willing to share some of the net benefits from the extracted resources with the second generation. If the first generation keeps net benefits of $40 (thereby making it just as well off as if equal amounts were extracted in each period) and saves the extra $0.466 (the $40.466 net benefits earned during the first period in the dynamic efficient allocation minus the $40 reserved for itself) at 10 percent interest for those in the next period, this savings would grow to $0.513 by the second period [0.466(1.10)]. Add this to the net benefits received directly from the dynamic efficient allocation ($39.512), and the second generation would receive $40.025. Those in the second period would be better off by accepting the dynamic efficient allocation with sharing than they would if they demanded that resources be allocated equally between the two periods.

This example demonstrates that although dynamic efficient allocations do not automatically satisfy sustainability criteria, they could be compatible with sustainability, even in an economy relying heavily on depletable resources. The possibility that the second period can be better off is not a guarantee; the required degree of sharing must take place. Example 5.1 points out that this sharing does sometimes take place, although, as we shall see, such sharing is more likely to be the exception than the norm. In subsequent chapters we shall examine both the conditions under which we could expect the appropriate degree of sharing to take place and the conditions under which it would not.

## Applying the Sustainability Criterion

One of the difficulties in assessing the fairness of intertemporal allocations using this version of the sustainability criterion is that it is so difficult to apply. Discovering whether the well-being of future generations is lower than that of current generations requires us not only to know something about the allocation of resources over time, but also to know something about the preferences of future generations (in order to establish how valuable various resource streams are to them). That is a tall (impossible?) order!

Is it possible to develop a version of the sustainability criterion that is more operational? Fortunately it is, thanks to what has become known as the "Hartwick Rule."

[6]The supporting calculations are (1.905)(10.238) + 0.5(4.095)(10.238) for the first period and (2.095)(9.762) + 0.5(3.905)(9.762) for the second period.

EXAMPLE 5.1

## The Alaska Permanent Fund

One interesting example of an intergenerational sharing mechanism currently exists in the State of Alaska. Extraction from Alaska's oil fields generates significant income, but it also depreciates one of the state's main environmental assets. To protect the interests of future generations as the Alaskan pipeline construction neared completion in 1976, Alaska voters approved a constitutional amendment that authorized the establishment of a dedicated fund: the Alaska Permanent Fund. This fund was designed to capture a portion of the rents received from the sale of the state's oil to share with future generations. The amendment requires:

> *At least 25 percent of all mineral lease rentals, royalties, royalty sales proceeds, federal mineral revenue-sharing payments and bonuses received by the state be placed in a permanent fund, the principal of which may only be used for income-producing investments.*

The principal of this fund cannot be used to cover current expenses without a majority vote of Alaskans.

The fund is fully invested in capital markets and diversified among various asset classes. It generates income from interest on bonds, stock dividends, real estate rents, and capital gains from the sale of assets. To date, the legislature has used some of these annual earnings to provide dividends to every eligible Alaska resident, while using the rest to increase the size of the principal, thereby assuring that it is not eroded by inflation.

Although this fund does preserve some of the revenue for future generations, two characteristics are worth noting. First, the principal could be used for current expenditures if a majority of current voters agreed. To date, that has not happened, but it has been discussed. Second, only 25% of the oil revenue is placed in the fund; assuming that revenue reflects scarcity rent, full sustainability would require dedicating 100% of it to the fund. Because the current generation not only gets its share of the income from the permanent fund, but also receives 75% of the proceeds from current oil sales, this sharing arrangement falls short of that prescribed by the Hartwick rule.

*Source:* The Alaska Permanent Fund Web site: http://www.apfc.org/homeobjects/tabpermfund.cfm/.

In an early article, John Hartwick (1977) demonstrated that a constant level of consumption could be maintained perpetually from an environmental endowment if all the scarcity rent derived from resources extracted from that endowment were invested in capital. That level of investment would be sufficient to assure that the value of the total capital stock would not decline.

Two important insights flow from this reinterpretation of the sustainability criterion. First, with this version it is possible to judge the sustainability of an allocation by examining whether or not the value of the total capital stock is nondeclining. That test can be performed each year without knowing anything about future allocations or preferences. Second, this analysis suggests the specific degree of sharing that would be necessary to produce a sustainable outcome, namely, all scarcity rent must be invested.

Let's pause to be sure we understand what is being said and why it is being said. Although we shall return to this subject later in the book, it is important now to have at least an intuitive understanding of the implications of this analysis. Consider an analogy. Suppose a grandparent left you an inheritance of $10,000, and you put it in a bank where it earns 10 percent interest.

What are the choices for allocating that money over time and what are the implications of those choices? If you spent exactly $1,000 per year, the amount in the bank would remain $10,000 and the income would last forever; you would be spending only the interest, leaving the principal intact. If you spend more than $1,000 per year, the principal would necessarily decline over time and eventually the balance in the account would go to zero. In the language of this chapter, spending $1,000 per year or less would satisfy the sustainability criterion, while spending more would violate the sustainability criterion.

What does the Hartwick Rule mean in this context? It suggests that one way to tell whether an allocation (spending pattern) is sustainable or not is to examine what is happening to the value of the principal over time. If the principal is declining, the allocation (spending pattern) is not sustainable. If the principal is increasing or remaining constant, the allocation (spending pattern) is sustainable.

How do we apply this logic to the environment? In general, the Hartwick Rule suggests that the current generation has been given an endowment. Part of the endowment consists of environmental and natural resources (known as "natural capital") and physical capital (such as buildings, equipment, schools, roads, and so on). Sustainable use of this endowment implies that we should keep the principal (the value of the endowment) intact and live off only the flow of services provided. We should not, in other words, chop down all the trees and use up all the oil, leaving future generations to fend for themselves. Rather we need to assure that the value of the total capital stock is maintained, not depleted.

The desirability of this version of the sustainability criterion depends crucially on how substitutable the two forms of capital are. If physical capital can readily substitute for natural capital, then maintaining the value of the sum of the two is sufficient. If, however, physical capital cannot completely substitute for natural capital, investments in physical capital may not be enough to assure sustainability.

How tenable is the assumption of complete substitutability between physical and natural capital? Clearly it is untenable for certain categories of environmental resources. Although we can contemplate the replacement of natural breathable air with universal air-conditioning in domed cities, both the expense and the artificiality of this approach make it an absurd compensation device. Obviously intergenerational compensation must be approached carefully (see Example 5.2).

Recognizing the weakness of the constant total capital definition in the face of limited substitution possibilities has led some economists to propose a new definition. According to this new definition an allocation is sustainable if it maintains the value of the stock of *natural* capital. This definition assumes that it is natural capital that drives future well-being, and further assumes that little or no substitution between physical and natural capital is possible. To differentiate these two definitions, the maintenance of the value of total capital is known as the "weak

EXAMPLE 5.2

## Nauru: Weak Sustainability in the Extreme

The weak sustainability criterion is used to judge whether the depletion of natural capital is offset by sufficiently large increases in physical or financial capital so as to prevent total capital from declining. It seems quite natural to suppose that a violation of that criterion does demonstrate *unsustainable* behavior. But does fulfillment of the weak sustainability criterion provide an adequate test of *sustainable* behavior? Consider the case of Nauru.

Nauru is a small Pacific island that lies some 3,000 kilometers northeast of Australia. It contains one of the highest grades of phosphate rock ever discovered. Phosphate is a prime ingredient in fertilizers.

Over the course of a century, first colonizers and then, after independence, the Nauruans decided to extract massive amounts of this rock. This decision has simultaneously enriched the remaining inhabitants (including the creation of a trust fund believed to contain over $1 billion) and destroyed most of the local ecosystems. Local needs are now mainly met by imports financed from the financial capital created by the sales of the phosphate.

However wise or unwise the choices made by the people of Nauru were, they could not be replicated globally. Everyone cannot subsist solely on imports financed with trust funds; every import must be exported by someone! The story of Nauru demonstrates the value of complementing the weak sustainability criterion with other, more demanding criteria. Satisfying the weak sustainability criterion may be a necessary condition for sustainability, but it is not always sufficient.

*Source*: J. W. Gowdy, and C. N. McDaniel. "The Physical Destruction of Nauru: An Example of Weak Sustainability," *Land Economics* Vol. 75, No. 2 (1999): 333–338.

sustainability" definition, while maintaining the value of natural capital is known as the "strong sustainability" definition.

A final definition, known as "environmental sustainability," requires that certain *physical flows* of certain key *individual* resources be maintained. This definition suggests that it is not sufficient to maintain the *value* of an *aggregate*. For a fishery, for example, this definition would require catch levels that did not exceed the growth of the biomass for the fishery. For a wetland, it would require the preservation of the specific ecological functions.

# Implications for Environmental Policy

In order to be useful guides to policy, our sustainability and efficiency criteria must be neither synonymous nor incompatible. Do these criteria meet that test?

They do. As we shall see later in the book, not all efficient allocations are sustainable and not all sustainable allocations are efficient. Yet some sustainable allocations are efficient and some efficient allocations are sustainable. Furthermore, market allocations may be either efficient or inefficient and either sustainable or unsustainable. Do these differences have any policy implications? Indeed they do. In particular they suggest a specific strategy for policy. Among the possible uses for resources that fulfill the sustainability criterion, we choose the one that maximizes either dynamic or static efficiency as appropriate. In this formulation the sustainability criterion acts as an overriding constraint on social decisions. Yet by itself, it is insufficient because it fails to provide any guidance on which of the infinite number of sustainable allocations should be chosen. That is where efficiency comes in. It provides a means for maximizing the wealth derived from all the possible sustainable allocations.

This combination of efficiency with sustainability turns out to be very helpful in guiding policy. Many unsustainable allocations are the result of inefficient behavior. Correcting the inefficiency can either restore sustainability or move the economy a long way in that direction. Furthermore, and this is important, correcting inefficiencies can frequently produce win-win situations. In win-win changes, the various parties affected by the change can all be made better off after the change than before. This contrasts sharply with changes in which the gains to the gainers are smaller than the losses to the losers.

Win-win situations are possible because moving from an inefficient to an efficient allocation increases net benefits. The increase in net benefits provides a means for compensating those who might otherwise lose from the change. Compensating losers reduces the opposition to change, thereby making change more likely. Do our economic and political institutions normally produce outcomes that are both efficient and sustainable? In upcoming chapters we will provide explicit answers to this important question.

## Summary

Both efficiency and ethical considerations can guide the desirability of private and social choices involving the environment. Whereas the former is concerned mainly with eliminating waste in the use of resources, the latter is concerned with assuring the fair treatment of all parties.

Previous chapters have focused on the static and dynamic efficiency criteria. Chapter 21 will focus on the environmental justice implications of environmental degradation and remediation for members of the current generation. This chapter examines one globally important characterization of the obligation previous generations owe to those generations that follow and the policy implications that flow from acceptance of that obligation.

The specific obligation examined in this chapter—sustainable development—is based upon the notion that earlier generations should be free to pursue their own well-being as long as in so doing they do not diminish the welfare of future generations. This notion gives rise to three alternative definitions of sustainable allocations:

**Weak Sustainability.** Resource use by previous generations should not exceed a level that would prevent subsequent generations from achieving a level of well-being at least as great. One of the implications of this definition is that the value of the capital stock (natural plus physical capital) should not decline. Individual components of the aggregate could decline in value as long as other components were increased in value (normally through investment) sufficiently to leave the aggregate value unchanged.

**Strong Sustainability.** According to this interpretation, the value of the remaining stock of natural capital should not decrease. This definition places special emphasis on preserving natural (as opposed to total) capital under the assumption that natural and physical capital offer limited substitution possibilities. This definition retains the focus of the previous definition on preserving value (rather than a specific level of physical flow) and on preserving an aggregate of natural capital (rather than any specific component).

**Environmental Sustainability.** Under this definition, the *physical* flows of *individual* resources should be maintained, not merely the *value* of the *aggregate*. For a fishery, for example, this definition would emphasize maintaining a constant fish catch (referred to as a sustainable yield), rather than a constant value of the fishery. For a wetland, it would involve preserving specific ecological functions, not merely their aggregate value.

It is possible to examine and compare the theoretical conditions that characterize various allocations (including market allocations and efficient allocations) to the necessary conditions for an allocation to be sustainable under these definitions. According to the theorem that is now known as the "Hartwick Rule," if all of the scarcity rent from the use of scarce resources is invested in capital, the resulting allocation will satisfy the first definition of sustainability.

In general, not all efficient allocations are sustainable and not all sustainable allocations are efficient. Furthermore, market allocations can be: (1) efficient, but not sustainable; (2) sustainable, but not efficient; (3) inefficient and unsustainable; and (4) efficient and sustainable. One class of situations, known as "win-win" situations, provides an opportunity to increase simultaneously the welfare of both current and future generations.

We shall explore these themes much more intensively as we proceed through the book. In particular we shall inquire into when market allocations can be expected to produce allocations that satisfy the sustainability definitions and when they cannot. We shall also see how the skillful use of economic incentives can allow policymakers to exploit "win-win" situations to promote a transition onto a sustainable path for the future.

## Discussion Question

1. The environmental sustainability criterion differs in important ways from both strong and weak sustainability. Environmental sustainability frequently means maintaining a constant physical flow of individual resources (for example, fish from the sea or wood from the forest), while the other two definitions call for maintaining the *aggregate value* of those service flows. When might the two criteria lead to different choices? Why?