

# 5

## Dynamic Efficiency and Sustainable Development

*We usually see only the things we are looking for—so much so that we sometimes see them where they are not*

—Eric Hoffer, *The Passionate State of Mind* (1993)

### Introduction

In previous chapters, we have developed two specific means for identifying environmental problems. The first, static efficiency, allows us to evaluate those circumstances where time is not a crucial aspect of the allocation problem. Typical examples might include allocating resources such as water or solar energy where next year's flow is independent of this year's choices. The second, more complicated criterion, dynamic efficiency, is suitable for those circumstances where time is a crucial aspect. One typical example might include the combustion of depletable resources such as oil, since supplies used now are unavailable for future generations.

After defining these criteria and showing how they could be operationally invoked, we demonstrated how helpful they can be. They are useful not only in identifying environmental problems and ferreting out their behavioral sources, but also in providing a basis for identifying types of remedies. These criteria even help design the various policy instruments that can be used to restore some sense of balance.

But the fact that these are powerful and useful tools in the quest for a sense of harmony between the economy and the environment does not imply that they are the only criteria in which we should be interested. In a general sense, the efficiency criteria are designed to prevent wasteful use of environmental and natural resources. That is a desirable attribute, but it is not the only possible desirable attribute. We might care, for example, not only about the value of the environment (the size of the pie), but also how this value is shared (the size of each piece to all recipients). In other words, fairness or justice concerns should accompany efficiency considerations.

In this chapter, we investigate one particular fairness concern—the treatment of future generations. We begin by considering a specific, ethically challenging situation—the allocation of a depletable resource over time. Using a numerical

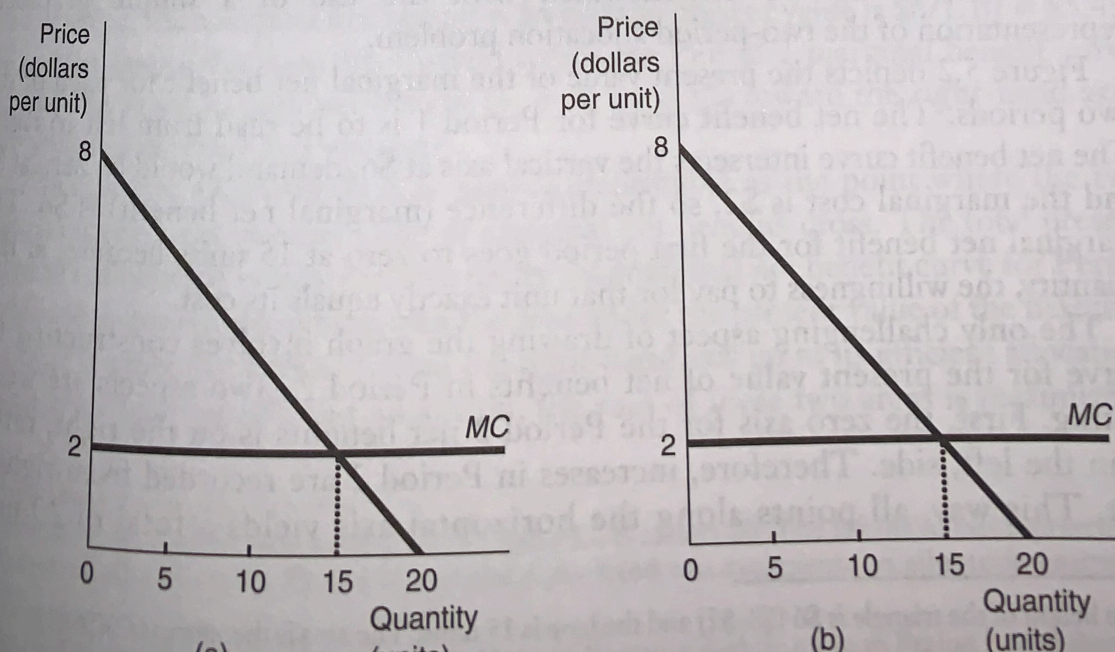
example, we shall trace out the temporal allocation of a depletable resource using the dynamic efficiency criterion and show how this allocation is affected by changes in the discount rate. To lay the groundwork for our evaluation of fairness, we then turn to the task of defining what we mean by intertemporal fairness. Finally, we consider not only how this theoretical definition can be made operationally measurable, but also how it relates to dynamic efficiency. To what degree is dynamic efficiency compatible with intergenerational fairness?

## A Two-Period Model

Dynamic efficiency balances present and future uses of a depletable resource by maximizing the present value of the net benefits derived from its use. This implies a particular allocation of the resource across time. We can investigate the properties of this allocation and the influence of such key parameters as the discount rate with the aid of a simple numerical example. We begin with the simplest of models—deriving the dynamic efficient allocation across two time periods. In subsequent chapters, we show how these conclusions generalize to longer time periods and to more complicated situations.

Assume that we have a fixed supply of a depletable resource to allocate between two periods. Assume further that the demand function is constant in the two periods, the marginal willingness to pay is given by the formula  $P = 8 - 0.4q$ , and marginal cost is constant at \$2 per unit (see Figure 5.1). Note that if the total supply was 30 or greater, and we were concerned only with these two periods, an efficient allocation would produce 15 units in each period, *regardless of the discount rate*.

FIGURE 5.1 The Allocation of an Abundant Depletable Resource: (a) Period 1 and (b) Period 2



Thirty units would be sufficient to cover the demand in both periods; the consumption in Period 1 does not reduce the consumption in Period 2. In this case the static efficiency criterion is sufficient because the allocations are not interdependent.

Examine, however, what happens when the available supply is less than 30. Suppose it equals 20. How do we determine the efficient allocation? According to the dynamic efficiency criterion, the efficient allocation is the one that maximizes the present value of the net benefit. The present value of the net benefit for both periods is simply the sum of the present values in each of the two periods. To take a concrete example, consider the present value of a particular allocation: 15 units in the first period and 5 in the second. How would we compute the present value of that allocation?

The present value in the first period would be that portion of the geometric area under the demand curve that is over the supply curve—\$45.00.<sup>1</sup> The present value in the second period is that portion of the area under the demand curve that is over the supply curve from the origin to the five units produced multiplied by  $1/(1+r)$ . If we use  $r = 0.10$ , then the present value of the net benefit received in the second period is \$22.73,<sup>2</sup> and the present value of the net benefits for the two years is \$67.73.

Having learned how to find the present value of net benefits for any allocation, how does one find the allocation that maximizes present value? One way, with the aid of a computer, is to try all possible combinations of  $q_1$  and  $q_2$  that sum to 20. The one yielding the maximum present value of net benefits can then be selected. That is tedious and, for those who have the requisite mathematics, unnecessary.

The dynamically efficient allocation of this resource has to satisfy the condition that the present value of the marginal net benefit from the last unit in Period 1 equals the present value of the marginal net benefit in Period 2 (see appendix at the end of this chapter). Even without mathematics, this principle is easy to understand, as can be demonstrated with the use of a simple graphical representation of the two-period allocation problem.

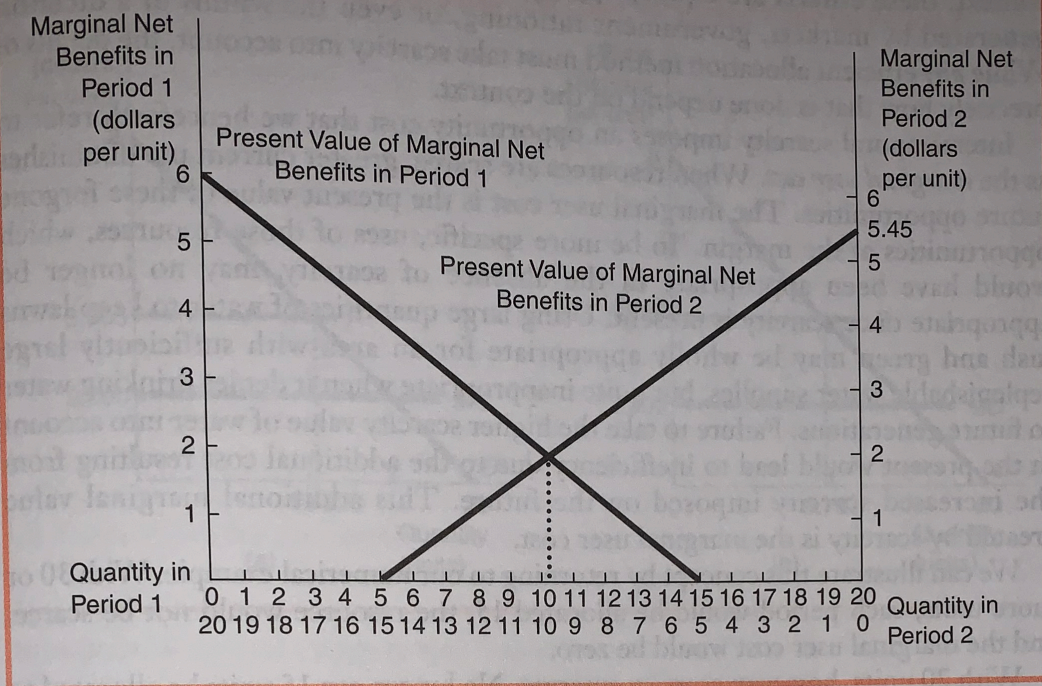
Figure 5.2 depicts the present value of the marginal net benefit for each of the two periods. The net benefit curve for Period 1 is to be read from left to right. The net benefit curve intersects the vertical axis at \$6; demand would be zero at \$8 and the marginal cost is \$2, so the difference (marginal net benefit) is \$6. The marginal net benefit for the first period goes to zero at 15 units because, at that quantity, the willingness to pay for that unit exactly equals its cost.

The only challenging aspect of drawing the graph involves constructing the curve for the present value of net benefits in Period 2. Two aspects are worth noting. First, the zero axis for the Period 2 net benefits is on the right, rather than the left, side. Therefore, increases in Period 2 are recorded from right to left. This way, all points along the horizontal axis yields a total of 20 units

<sup>1</sup>The height of the triangle is \$6 [ $\$8 - \$2$ ] and the base is 15 units. The area is therefore  $(1/2)(\$6)(15) = \$45$ .

<sup>2</sup>The undiscounted net benefit is \$25. The calculation is  $(6 - 2) \times 5 + 1/2(8 - 6) \times 5 = \$25$ . The discounted net benefit is therefore  $25/1.10 = 22.73$ .

FIGURE 5.2 The Dynamically Efficient Allocation



allocated between the two periods. Any point on that axis picks a unique allocation between the two periods.<sup>3</sup>

Second, the present value of the marginal benefit curve for Period 2 intersects the vertical axis at a different point than does the comparable curve in Period 1. (Why?) This intersection is lower because the marginal benefits in the second period need to be discounted (multiplied by  $1/(1+r)$ ) to convert them into present value form since they occur one year later. Thus, with the 10 percent discount rate we are using, the marginal net benefit is \$6 and the present value is  $\$6/1.10 = \$5.45$ . Note that larger discount rates would rotate the Period 2 marginal benefit curve around the point of zero net benefit ( $q_1 = 5, q_2 = 15$ ) toward the right-hand axis. We shall use this fact in a moment.

The efficient allocation is now readily identifiable as the point where the two curves representing present value of marginal net benefits cross. The total present value of net benefits is then the area under the marginal net benefit curve for Period 1 up to the efficient allocation, plus the area under the present value of the marginal net benefit curve for Period 2 from the right-hand axis up to its efficient allocation. Because we have an efficient allocation, the sum of these two areas is maximized.<sup>4</sup>

<sup>3</sup>Note that the sum of the two allocations in Figure 5.2 is always 20. The left-hand axis represents an allocation of all 20 units to Period 2, and the right-hand axis represents an allocation entirely to Period 1.

<sup>4</sup>Demonstrate that this point is the maximum by first allocating slightly more to Period 2 (and therefore less to Period 1) and showing that the total area decreases. Conclude by allocating slightly less to Period 2 and showing that, in this case as well, total area declines.

Since we have developed our efficiency criteria independent of an institutional context, these criteria are equally appropriate for evaluating resource allocations generated by markets, government rationing, or even the whims of a dictator. While *any* efficient allocation method must take scarcity into account, the details of precisely how that is done depend on the context.

Intertemporal scarcity imposes an opportunity cost that we henceforth refer to as the *marginal user cost*. When resources are scarce, greater current use diminishes future opportunities. The marginal user cost is the present value of these forgone opportunities at the margin. To be more specific, uses of those resources, which would have been appropriate in the absence of scarcity, may no longer be appropriate once scarcity is present. Using large quantities of water to keep lawns lush and green may be wholly appropriate for an area with sufficiently large replenishable water supplies, but quite inappropriate when it denies drinking water to future generations. Failure to take the higher scarcity value of water into account in the present would lead to inefficiency due to the additional cost resulting from the increased scarcity imposed on the future. This additional marginal value created by scarcity is the marginal user cost.

We can illustrate this concept by returning to our numerical example. With 30 or more units, each period would be allocated 15, the resource would not be scarce, and the marginal user cost would be zero.

With 20 units, however, scarcity emerges. No longer can 15 units be allocated to each period; each period will have to be allocated less than would be the case without scarcity. Due to this scarcity the marginal user cost for this case is not zero. As can be seen from Figure 5.2, the present value of the marginal user cost, the additional value created by scarcity, is graphically represented by the vertical distance between the quantity axis and the intersection of the two present-value curves. It is identical to the present value of the marginal net benefit in each of the periods. This value can either be read off the graph or determined more precisely, as demonstrated in the chapter appendix, to be \$1.905.

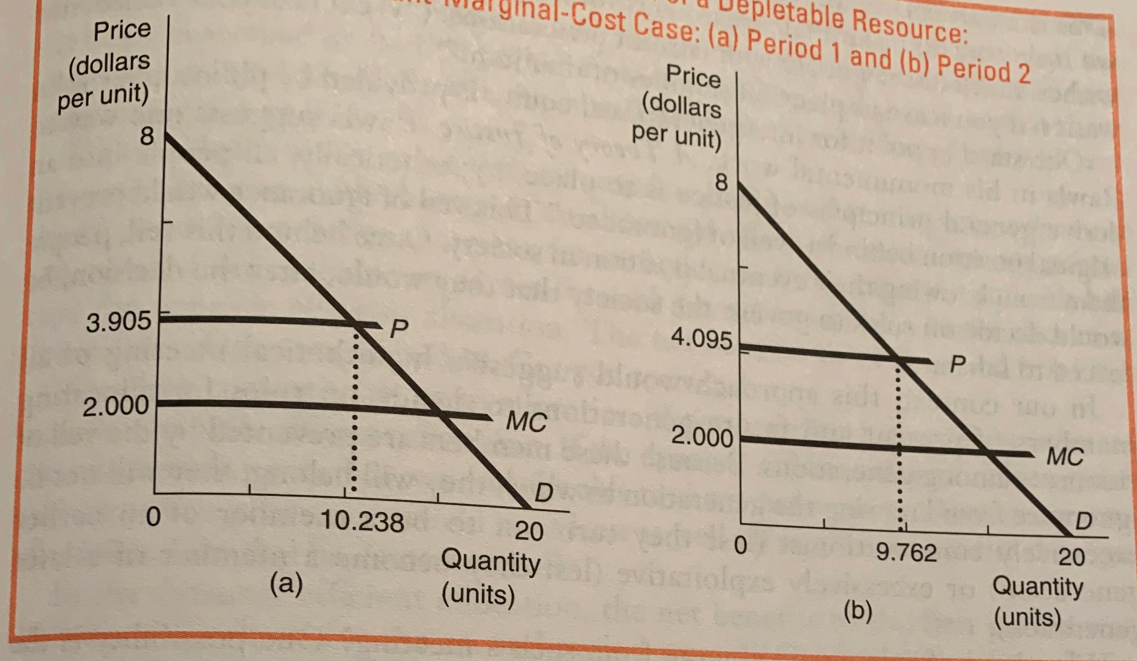
We can make this concept even more concrete by considering its use in a market context. An efficient market would have to consider not only the marginal cost of extraction for this resource but also the marginal user cost. Whereas in the absence of scarcity, the price would equal only the marginal cost of extraction, with scarcity, the price would equal the sum of marginal extraction cost and marginal user cost.

To see this, solve for the prices that would prevail in an efficient market facing scarcity over time. Inserting the efficient quantities (10.238 and 9.762, respectively) into the willingness-to-pay function ( $P = 8 - 0.4q$ ) yields  $P_1 = 3.905$  and  $P_2 = 4.095$ . The corresponding supply-and-demand diagrams are given in Figure 5.3. Compare Figure 5.3 with Figure 5.1 to see the impact of scarcity on price. Note that in the absence of scarcity, marginal user cost is zero.

In an efficient market, the marginal user cost for each period is the difference between the price and the marginal cost of extraction. Notice that it takes the value \$1.905 in the first period and \$2.095 in the second. In both the periods, the present value of the marginal user cost is \$1.905. In the second period, the actual marginal user cost is  $\$1.905(1 + r)$ . Since  $r = 0.10$  in this example, the marginal user cost for

FIGURE 5.3

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



the second period is \$2.095.<sup>5</sup> Thus, while the present value of marginal user cost is equal in both periods, the actual marginal user cost rises over time.

Both the size of the marginal user cost and the allocation of the resource between the two periods is affected by the discount rate. In Figure 5.2, because of discounting, the efficient allocation allocates somewhat more to Period 1 than to Period 2. A discount rate larger than 0.10 would be incorporated in this diagram by rotating the Period 2 curve an appropriate amount toward the right-hand axis, holding fixed 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?

<sup>5</sup> \$2.095 and showing it to be equal to \$1.905.