4. Economic Efficiency and the Environment

4.1 Efficiency as Surplus Maximization

For the most part we will define efficiency in terms of surplus maximization. Recall that social surplus is maximized if it is not possible to find a re-allocation such that the gains to the winners (the benefits of the reallocation) more than offset the losses to the losers (the costs of the reallocation). An allocation is efficient if it has the highest social surplus of any feasible allocation.

Let z denote the resource to be allocated. Then we will denote the efficient allocation by z^*. If social surplus is twice continuously differentiable and concave in z then a necessary condition for z^* is

$$MSC(z^*) = MSB(z^*) \tag{4.1}$$

where *MSC* denotes marginal social cost and *MSB* denotes marginal social benefit. For most of our analysis we will take this condition as our efficiency condition (although we will sometimes need to be more careful about sufficient conditions).

Condition (4.1) states that we should allocate resources in such a way that the marginal benefit and marginal cost of any reallocation are just equated. The logic can be seen most clearly in figure 4.1.

The *MSB* schedule represents the marginal social benefit associated with devoting resources to a particular activity z. The *MSC* schedule represents the marginal social cost of devoting resources to that activity (the benefit foregone by not devoting those resources to some alternative use).

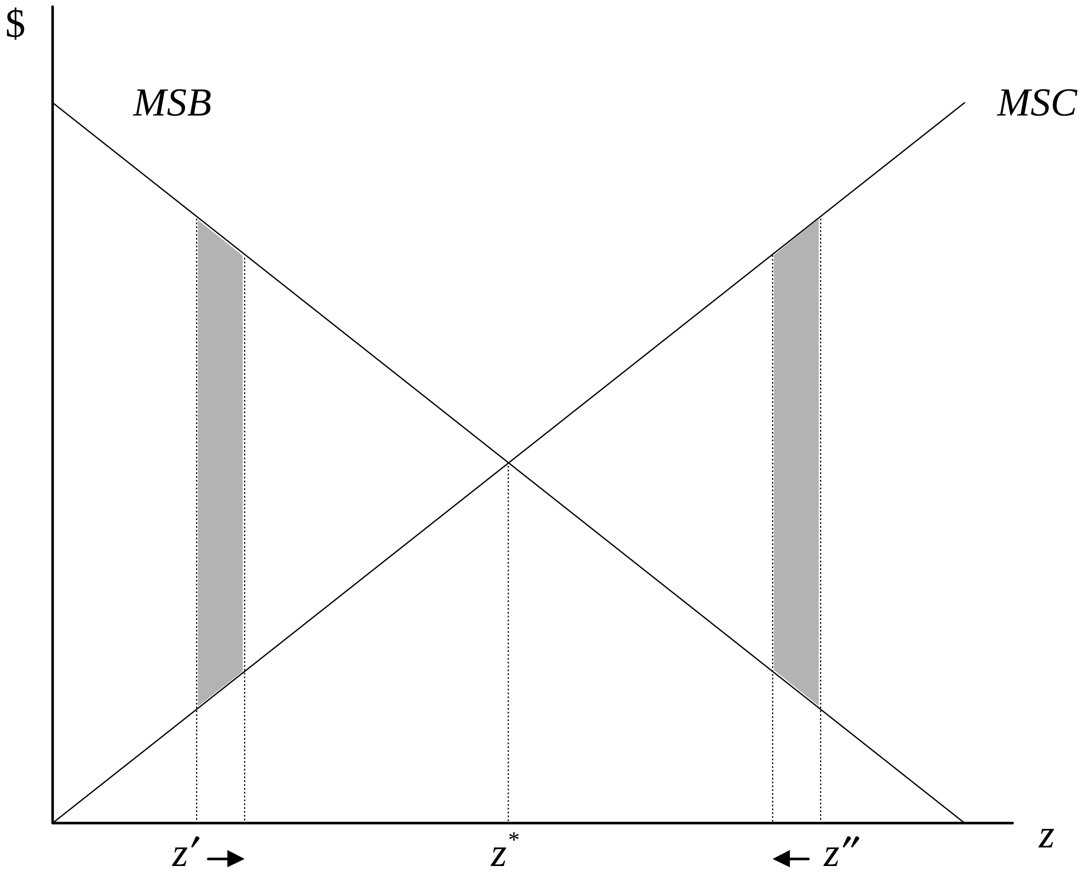

Figure 4.1

The negative slope of the *MSB* schedule reflects diminishing marginal benefit from this activity (that is, each increment to the level of the activity yields a benefit smaller than the previous increment). The positive slope of the *MSC* schedule reflects the increasing cost of taking resources away from some alternative activity (the marginal benefit from which increases as less is undertaken).

Suppose we choose a level of activity $z' < z^*$. Then a small increase in z will yield a benefit equal to $MSB(z')$ (that is, *MSB* evaluated at z') and a cost equal to $MSC(z') < MSB(z')$. That is, social surplus could be increased by an amount equal to the shaded region above z' if z is increased by one unit. Further increases up to z^* will continue to raise surplus.

Now suppose instead we choose a level of activity $z'' > z^*$. In this case, a reduction in z will mean a reduced benefit equal to $MSB(z'')$ but an even larger reduction in cost, since $MSC(z'') > MSB(z'')$. Again, surplus would be increased by the change. Only at z^* is it not possible to create more surplus by changing the level of z. Thus, z^* is efficient.

4.2 Efficient Pollution

We will focus much of our attention in this course on the question of pollution and its regulation. It will therefore be useful to illustrate the application of our efficiency criterion in the pollution context.

Recall that any activity that consumes resources must generate waste (by the 1st law of thermodynamics). Our concern is with that waste which is not assimilated: *pollution* is defined as waste in excess of assimilative capacity. We will henceforth refer to the waste produced from some activity as *emissions*.

The efficient level of pollution is that which just balances the costs imposed by pollution against the benefits derived from the activity that produces the emissions. We will refer to the costs of pollution as *environmental damage* (or sometimes as just damage). We will refer to the benefits foregone when waste is reduced as *abatement cost*.

The costs of pollution include human health costs, amenity costs (such as a spoiled view), materials damage, biological damage (such as species loss or harm), and damage to assimilative capacity itself (which may have long term implications). It is crucial to understand that our definition of environmental damage includes *all* costs associated with pollution.

The cost of abating pollution may involve a reduction in the activity that produces the emissions, or the use of some waste-reducing measures, or some combination of the two. (For example, auto emissions could be reduced by less driving, by smoother driving, or a combination of the two). Abatement cost is defined as the least-cost combination of measures to reduce emissions. (In chapter 6 we will consider the possibility of employing less polluting technologies to produce the valued activity, such as the adoption of electric cars).

The efficient level of emissions (with an implied efficient level of pollution) is that which maximizes social surplus. If abatement cost is twice continuously differentiable and concave in emissions, and damage is twice continuously differentiable and convex in emissions, then we can characterize the efficient level of emissions as e^* such that

$$MAC(e^*) = MD(e^*) \tag{4.2}$$

where *MAC* denotes *marginal abatement cost*, and *MD* denotes *marginal damage*. This condition is represented graphically in figure 4.2.

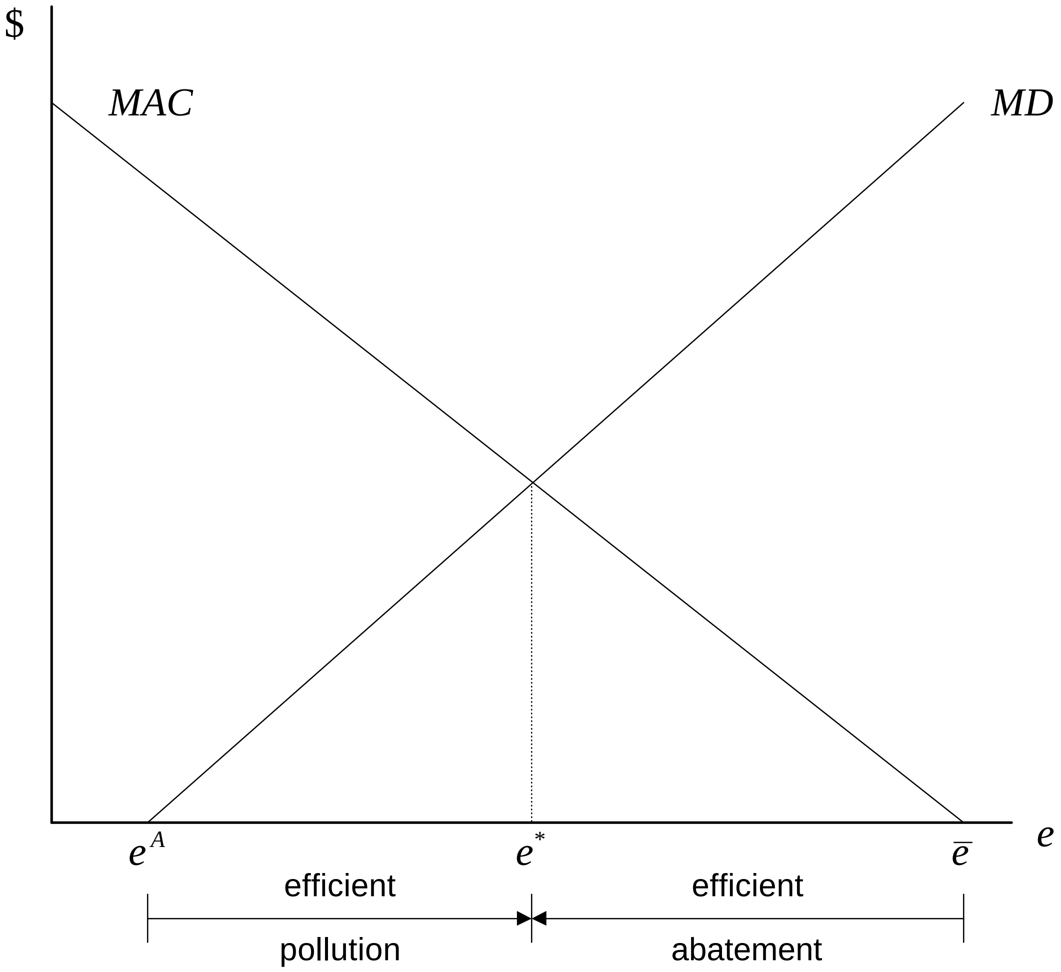

Figure 4.2

Strict concavity of abatement cost (the negative slope of *MAC* in figure 4.2) reflects the fact that foregoing the valued activity that generates the emissions or finding alternative ways to reduce emissions becomes increasingly difficult and costly. (For example, driving more smoothly or combining trips and car-pooling can reduce auto emissions without great cost but substantial reductions in car use will impose significant costs on would-be drivers).

Strict convexity of the damage function (the positive slope of *MD* in figure 4.2) reflects the presence of threshold tolerances in various elements of the ecosystem. Note that *MD* is zero at levels of waste below assimilative capacity, e^A.

Note that figure 4.2 depicts a case where the efficient level of pollution is positive: $e^* > e^A$. That is, the benefits associated with the activity are high enough to warrant incurring some environmental damage. This need not be the case. If marginal damage is infinite then *MD* is vertical at e^A, and e^A is the efficient level of emissions; zero pollution is efficient in that case.

In less extreme cases the efficient level of pollution is not zero; it will generally be positive. This represents a balance of two extreme possibilities: one that pays no heed to environmental damage (which would indicate a level of emissions equal to $\bar{e}$), and one that pays no heed to the costs associated with foregoing a valued activity (which would indicate a level of emissions equal to or below e^A). The efficient level of emissions is that which balances these costs and benefits.

4.3 Efficiency with Multiple Sources

It is useful to think in terms of a two stage process for characterizing the efficient solution:

(i) choose the emissions for each source to achieve a given target level of aggregate emissions at minimum abatement cost;

(ii) choose the target level of aggregate emissions to maximize social surplus.

Stage one: minimizing abatement cost

Suppose we wish to achieve a target level of aggregate emissions $\hat{E}$ at minimum abatement cost. This requires that the emissions from each source be chosen so that marginal abatement costs are equated across sources. To see why this is so, consider an example with just two sources.

Suppose these two sources have different marginal abatement cost schedules, as illustrated in figure 4.3. Such a situation may arise because source 1 places a higher value on the emission-generating activity than source 2, or because source 1 has an older, more polluting technology than source 2.

Suppose the aggregate emissions target is initially met by assigning half of the target to each source: $e_1 = \hat{E}/2$ and $e_2 = \hat{E}/2$. This allocation is illustrated in figure 4.3.

This allocation does not minimize total abatement cost. To see this, suppose we increase the emissions allocation for source 1 by one unit and reduce the allocation for source 2 by one unit. (Note that the aggregate target is still met). The associated changes in abatement costs for the two sources are illustrated as the shaded areas in figure 4.3. Abatement cost for source 2 rises by ΔAC_2 but abatement cost for source 1 falls by ΔAC_1. The total abatement cost across the two sources falls. Thus, the initial allocation could not have been one that minimized total abatement cost.

Figure 4.4 illustrates an allocation in which the emissions for each source are set so that marginal abatement costs are equated:

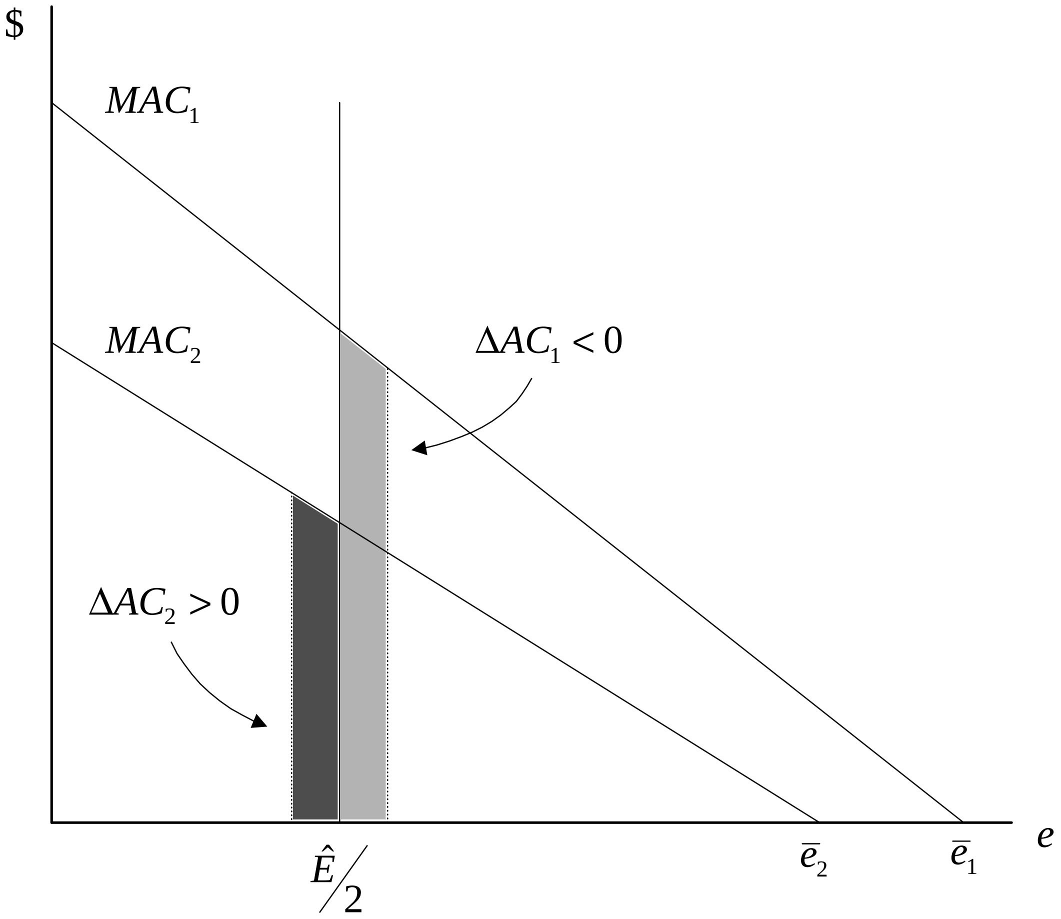

Figure 4.3

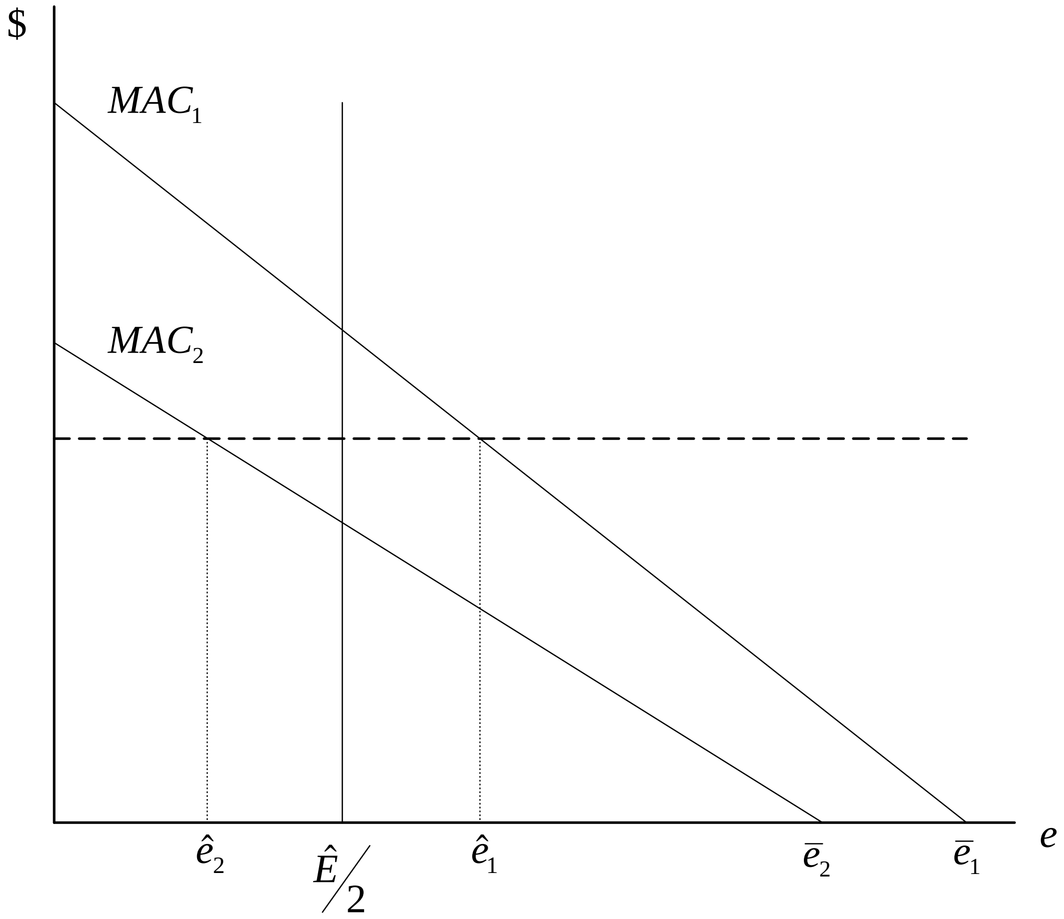

Figure 4.4

$$(4.3) \qquad MAC_1(\hat{e}_1) = MAC_2(\hat{e}_2) \text{ such that } \hat{e}_1 + \hat{e}_2 = \hat{E}$$

From this allocation it is not possible to further reduce total abatement cost. In general, if marginal abatement cost is increasing for all sources, then total abatement cost for meeting a given aggregate emissions target is minimized when emissions for each source are such that marginal abatement costs are equated across sources.

Stage two: maximizing social surplus

The problem in this stage is to choose the aggregate emissions target *E* to maximize social surplus. The surplus maximization problem can be cast as one of minimizing the sum of abatement cost and damage (since abatement cost represents benefits foregone when emissions are reduced).

We have seen in section 4.2 that for a single source the solution to the problem is to set e^* so that $MAC(e^*) = MD(e^*)$. The same basic result extends to the case of multiple sources. The optimal level of aggregate emissions when there are two sources is given by E^* such that

$$(4.4) \qquad MAC_1(e_1^*) = MAC_2(e_2^*) = MD(E^*) \text{ and } e_1^* + e_2^* = E^*$$

The first part of this condition follows from equation (4.3): total abatement cost must be minimized at the social optimum. To understand the second part of the condition, consider an allocation where it does not hold. Such an allocation is illustrated in figure 4.5. In this case we have an allocation where

$$(4.5) \qquad MAC_1(e_1^*) = MAC_2(e_2^*) < MD(E^*) \text{ and } \hat{e}_1 + \hat{e}_2 = \hat{E}$$

From this allocation it is possible to reduce e_1 *and* e_2, with a consequent increase in abatement cost equal to the sum of the shaded areas under the *MAC* schedules, and

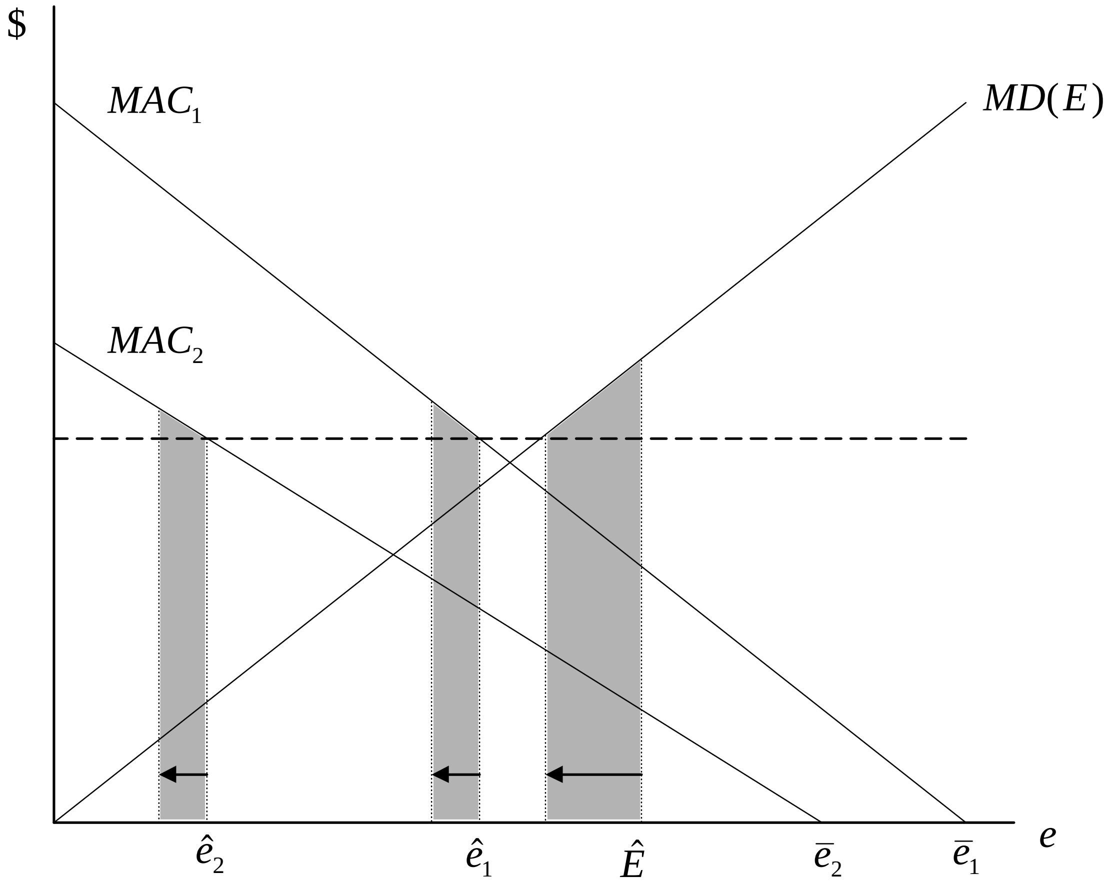

Figure 4.5

thereby reduce damage by an amount equal to the shaded area under the $MD(E)$ schedule. The reduction in damage more than offsets the increase in total abatement cost, and social surplus is thereby increased.

Figure 4.6 illustrates an optimal allocation corresponding to equation (4.5). From this allocation it is not possible to make social surplus larger by any reallocation. (Consider the same experiment we conducted in figure 4.5 to confirm this).

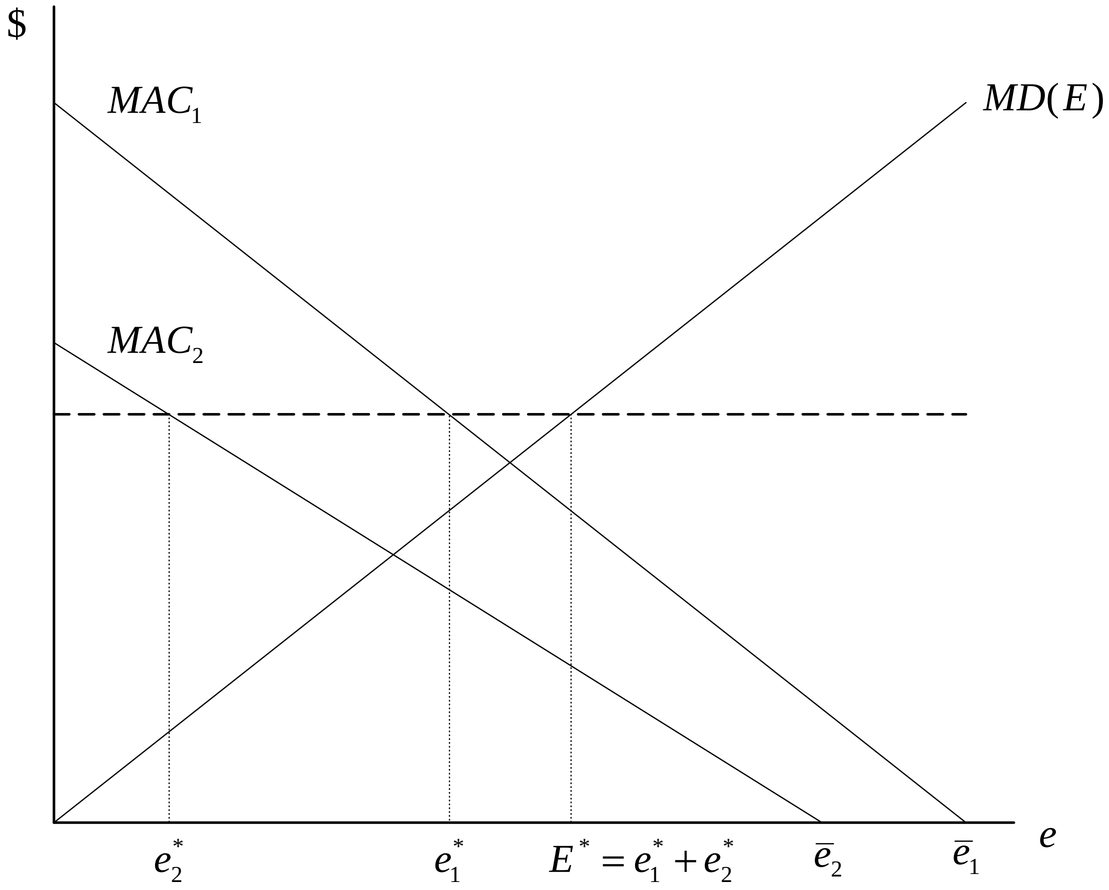

Figure 4.6