Chapter 18
Externalities and Public Goods

■ Questions for Review

1. **Which of the following describes an externality and which does not? Explain the difference.**

   a. **A policy of restricted coffee exports in Brazil causes the U.S. price of coffee to rise—an increase which in turn also causes the price of tea to rise.**

      Externalities cause inefficiencies because the price of the good does not reflect the true social value of the good. A policy of restricting coffee exports in Brazil causes the U.S. price of coffee to rise because supply is reduced. As the price of coffee rises, consumers switch to tea, thereby increasing the demand for tea, and hence increasing the price of tea. These are market effects, not externalities.

   b. **An advertising blimp distracts a motorist who then hits a telephone pole.**

      The advertising blimp is producing information. However, its method of supplying this information can be distracting for some consumers, such as those who happen to be driving. The blimp is creating a negative externality that influences drivers' safety. Since the price the advertising firm charges its client does not incorporate the externality of distracting drivers, too much of this type of advertising is produced from the point of view of society as a whole.

2. **Compare and contrast the following three mechanisms for treating pollution externalities when the costs and benefits of abatement are uncertain: (a) an emissions fee, (b) an emissions standard, and (c) a system of transferable emissions permits.**

   The choice between an emissions fee and an emissions standard depends on the marginal cost and marginal benefit of reducing pollution. First, suppose small changes in abatement yield large benefits while adding little to cost. In this case, if an emissions fee is set too low because of uncertainty, the firm will produce far too many emissions, so a standard is better. However, if small changes in abatement yield little benefit while adding greatly to cost, the cost of reducing emissions is high. In this case, fees should be used because setting a standard too high (due to uncertainty) yields little benefit but increases costs way beyond the efficient level.

   A system of transferable emissions permits combines the features of fees and standards to reduce pollution. Under this system, a standard is set and fees are used to transfer permits to firms that value them the most (i.e., firms with high abatement costs). However, because of uncertainty, the total number of permits can be incorrectly chosen. Too few permits will reduce emissions to inefficiently low levels and create excess demand for the permits, increasing their price and inefficiently diverting resources to owners of the permits.

   Typically, pollution control agencies implement one of the three mechanisms, measure the results, reassess the success of their choice, then reset new levels of fees or standards or select a new policy tool.

3. When do externalities require government intervention? When is such intervention unlikely to be necessary?

Economic efficiency can be achieved without government intervention when the externality affects a small number of people so that bargaining costs are small. As the Coase theorem tells us, the resulting outcome will be efficient in this case regardless of how property rights are specified. When these conditions are not met, government intervention is often required.

4. Consider a market in which a firm has monopoly power. Suppose in addition that the firm produces under the presence of either a positive or a negative externality. Does the externality necessarily lead to a greater misallocation of resources?

In the presence of a negative externality, a competitive market produces too much output compared to the socially optimal amount. But a monopolist restricts output, so it is possible that the monopolist will produce an output closer to the socially optimal solution. In the case of a positive externality, competitive firms produce too little output. Because a monopolist produces even less output, the monopolist causes a greater misallocation of resources.

5. Externalities arise solely because individuals are unaware of the consequences of their actions. Do you agree or disagree? Explain.

Disagree. It is not that people are unaware but that they have no economic incentive to consider and account for all of the consequences of their actions. If a firm dumps waste into a river that affects a swimming area downstream, it is generating a negative externality for the people downstream. This action maximizes the firm's profit if the firm incurs no private costs for dumping and is not forced to consider the external costs it is imposing on users of the swimming area. This is true whether the firm is aware of these social costs or not.

6. To encourage an industry to produce at the socially optimal level, the government should impose a unit tax on output equal to the marginal cost of production. True or false? Explain.

This statement is false. While a tax can encourage firms to produce at the socially optimal level, the tax should be set equal to the marginal external cost and not the marginal private cost. Competitive firms will maximize profit by producing at the point where price is equal to marginal cost. When there are external costs involved, the marginal private cost of the firm is too low from society's point of view, and as a result too much output is produced. By setting a tax equal to the additional social cost not being realized by the firm (the marginal external cost) the firm will be encouraged to consider all costs and will reduce output because the tax will increase its overall marginal cost.

7. George and Stan live next door to each other. George likes to plant flowers in his garden, but every time he does, Stan's dog comes over and digs them up. Stan's dog is causing the damage, so if economic efficiency is to be achieved, it is necessary that Stan pay to put up a fence around his yard to confine the dog. Do you agree or disagree? Explain.

Disagree. Economic efficiency does not require that Stan pay for the fence; it merely requires that Stan and George resolve the problem so that social welfare (total benefits less total costs) is maximized, regardless of who pays for it. For example, George and Stan could split the cost of a fence, George could pay Stan to get rid of his dog, or Stan could pay George not to plant flowers.

Given typical property rights, it seems likely that George could sue Stan and that a court would require Stan to pay for a fence or get rid of his dog. And it seems fair that Stan should have to do this, but it is not required for economic efficiency.

8. An emissions fee is paid to the government, whereas an injurer who is sued and held liable pays damages directly to the party harmed by an externality. What differences in the behavior of victims might you expect to arise under these two arrangements?

When victims can receive the damages directly, they are more likely to file a claim, initiate a suit, and try to overstate their damages. When victims do not receive the damages directly, they are less likely to report violations and are less likely to overstate their damages. In theory, emissions fees paid to the government equal the damage inflicted on others and hence move firms toward the socially optimal level of production. But since the fees are paid to the government rather than to the individuals who were injured, the affected individuals are less likely to file a complaint than they would if they received compensation for the damages directly.

9. Why does free access to a common property resource generate an inefficient outcome?

Free access to a resource means that the marginal cost to the user is less than the marginal social cost, because each user has no incentive to consider how his use of the resource will affect the use of the resource by others. The use of a common property resource by a person or firm reduces others' use of it. For example, the use of water by one consumer restricts its use by another. Since private marginal cost is below social marginal cost, too much of the resource is consumed by the individual user, creating an inefficient outcome. Each individual using the common property resource considers only his own actions and does not consider how all of the users collectively are affecting the resource.

10. Public goods are both nonrival and nonexclusive. Explain each of these terms and show clearly how they differ from each other.

A good is *nonrival* if, for any level of production, the marginal cost of providing the good to an additional individual is zero (although the cost to produce an additional unit could be greater than zero). A good is *nonexclusive* if it is impossible or very expensive to exclude individuals from consuming it once it is available to one individual. Public goods are *nonrival* and *nonexclusive*. Good examples are national defense, a lighthouse, and public television. Some goods are nonrival but exclusive such as a bridge during low traffic periods. One more person can use the bridge without any additional cost to the bridge authority and without imposing costs on other drivers in the form of congestion, but the bridge authority can exclude users by setting up tollbooths. Some goods are nonexclusive but rival. For example, a large lake can be nonexclusive because anyone can use it, but the more people there are fishing, the fewer fish are available to others, so it is rival.

11. A village is located next to 1000 acres of prime grazing land. The village presently owns the land and allows all residents to graze cows freely. Some members of the village council have suggested that the land is being overgrazed. Is this likely to be true? These same members have also suggested that the village should either require grazers to purchase an annual permit or sell off the land to the grazers. Would either of these be a good idea?

It is true that the common land is likely to be overgrazed since each individual will consider only their own private cost and not the total social cost of grazing. The social cost of grazing is likely to be higher than any one individual's private cost because no one individual has an incentive to take into account how his grazing affects the opportunities of others. As a result, conservation efforts by individuals are pointless.

For example, one individual could decide to graze only in certain areas during certain times of the year, while preserving other areas for other times of the year. However, the individual will not do this if the resource is common property as any other grazer can come along and freely disrupt the preservation system that the individual has set up.

Selling annual permits may help, but an annual permit will exclude only those grazers whose total benefits are less than the price of the permit. Anyone who buys the permit will still have the same

incentive to overgraze the commons. Selling the land outright is a better solution to the overgrazing problem. If an individual purchases the land she will then have an incentive to consider all of the costs associated with using the land, and as a result will use it in such a way that the resource is preserved, since she alone captures all of the benefits of preserving the resource. Another possibility would be to charge users based on the amount of grazing their cows do. If the grazing fee were set correctly, the efficient amount of grazing could be induced. However, it might be difficult to determine the correct fee, and the village would have to keep track of each resident's grazing and bill him or her accordingly.

12. Public television is funded in part by private donations, even though anyone with a television set can watch for free. Can you explain this phenomenon in light of the free rider problem?

The free rider problem refers to the difficulty of excluding people from consuming a nonexclusive commodity. Non-paying consumers can "free-ride" on commodities provided by paying customers. Public television is funded in part by contributions. Some viewers contribute, but most watch without paying, hoping that someone else will pay so they will not have to. To combat this problem these stations ask consumers to assess their true willingness to pay and ask them to contribute up to this amount. They then attempt to make those people feel good about their actions and make everyone else feel guilty for free riding.

13. Explain why the median voter outcome need not be efficient when majority-rule voting determines the level of public spending.

The median voter is the citizen with the middle preference: half the voting population is more strongly in favor of the issue and half is more strongly opposed. Under majority-rule voting, where each citizen's vote is weighted equally, the preferred spending level on public-goods provision of the *median voter* will win an election against any other alternative. However, majority rule is not necessarily efficient, because it gives each citizen's preferences equal weight. For an efficient outcome, we would need a system that measures and aggregates the willingness to pay of those citizens consuming the public good. Majority rule is not this system. However, as we have seen in previous chapters, majority rule is equitable in the sense that all citizens are treated equally. Thus, we again find a trade-off between equity and efficiency.

14. Would you consider Wikipedia a public good? Does it provide any positive or negative externalities?

Wikipedia (www.wikipedia.org) is a free online encyclopedia that is written and edited primarily by anonymous Internet volunteers who are not paid for doing so. To determine whether it is a public good, recall that public goods are nonrival and nonexclusive. Wikipedia is nonrival because the cost of providing the service to one more user is essentially zero. However, even though it is free, it is not inherently a nonexclusive good because it would be possible to exclude people from consuming the service if Wikipedia required a user fee or some other condition (such as volunteering to write or edit) to use the product. Therefore Wikipedia does not appear to be a public good in the full sense of the term.

An externality occurs when an action by a consumer or producer affects other consumers and/or producers, but is not accounted for in the market price. Since users benefit from the information they glean from Wikipedia but don't have to pay for it, there are positive externalities. There may also be negative externalities to the extent that the information provided by Wikipedia makes it easier for students to plagiarize when writing research papers. This imposes a cost on instructors who must check student work for such behavior.

■ Exercises

1. **A number of firms have located in the western portion of a town after single-family residences took up the eastern portion. Each firm produces the same product and in the process emits noxious fumes that adversely affect the residents of the community.**

   a. **Why is there an externality created by the firms?**

      The noxious fumes emitted by the firms impose costs on the town's residents, and the residents have no control over the quantity of the fumes. Costs may include reduced visibility, difficulty breathing, foul-smelling air, increased health problems, and reduced property values. The firms, however, do not have to pay to release the fumes, so the costs borne by the town's residents are not reflected in the firms' costs or the prices of their products. Thus there is a negative externality created by the firms.

   b. **Do you think that private bargaining can resolve the problem? Explain.**

      If residents anticipated the location of the firms when the eastern part of the town was developed, housing prices would have reflected the disutility of the fumes, and the externality would have been internalized by the housing market in housing prices. In this case there is no problem. If the noxious fumes were not anticipated, private bargaining could resolve the problem of the externality only if there are a relatively small number of parties (both firms and families). Private bargaining would rely on each family's willingness to pay for air quality, but truthful revelation might not be possible. All this will be complicated by the adaptability of the production technology known to the firms and the employment relations between the firms and families. It is unlikely that private bargaining will resolve the problem.

   c. **How might the community determine the efficient level of air quality?**

      The community could determine the economically efficient level of air quality by aggregating the families' willingness to pay and equating it with the marginal cost of pollution reduction. Both steps involve the acquisition of truthful information, which is likely to be quite difficult.

2. **A computer programmer lobbies against copyrighting software, arguing that everyone should benefit from innovative programs written for personal computers and that exposure to a wide variety of computer programs will inspire young programmers to create even more innovative programs. Considering the marginal social benefits possibly gained by this proposal, do you agree with this position?**

   Computer software is an example of a public good. Since it can be costlessly copied, the marginal cost of providing software to an additional user is near zero. Therefore, software is nonrival. (The fixed costs of creating software are high, but the variable costs are low.) Furthermore, it is expensive to exclude consumers from copying and using software because copy protection schemes are available only at high cost or high inconvenience to users. Therefore, software is by and large nonexclusive. As both nonrival and substantially nonexclusive, computer software suffers the problems of public goods provision: the presence of free riders makes it difficult or impossible for markets to provide the efficient level of software. Rather than regulating this market directly, the legal system guarantees property rights to the creators of software. If copyright protection were not enforced, it is likely that the software market would collapse, or that there would be a significant decrease in the quantity of software developed and supplied, which would reduce social benefits. The young programmers would not be inspired to create even more innovative programs because

there would be no private reward for doing so. Therefore, you should not agree with the computer programmer.

3. Assume that scientific studies provide you with the following information concerning the benefits and costs of sulfur dioxide emissions:

Benefits of abating (reducing) emissions: $MB = 500 - 20A$

Costs of abating emissions: $MC = 200 + 5A$

where A is the quantity abated in millions of tons and the benefits and costs are given in dollars per ton.

a. What is the socially efficient level of emissions abatement?

To find the socially efficient level of emissions abatement, set marginal benefit equal to marginal cost and solve for A:

$$500 - 20A = 200 + 5A$$

$$A = 12 \text{ million tons.}$$

b. What are the marginal benefit and marginal cost of abatement at the socially efficient level of abatement?

Substitute $A = 12$ into the marginal benefit and marginal cost functions to find the marginal benefit and cost:

$$MB = 500 - 20(12) = 260$$

$$MC = 200 + 5(12) = 260.$$

c. What happens to net social benefits (benefits minus costs) if you abate one million more tons than the efficient level? One million fewer?

Net social benefit is the area under the marginal benefit curve minus the area under the marginal cost curve. At the socially efficient level of abatement this is equal to area $a + b + c + d$ in the figure below, or

$$0.5(500 - 200)(12) = \$1800 \text{ million.}$$

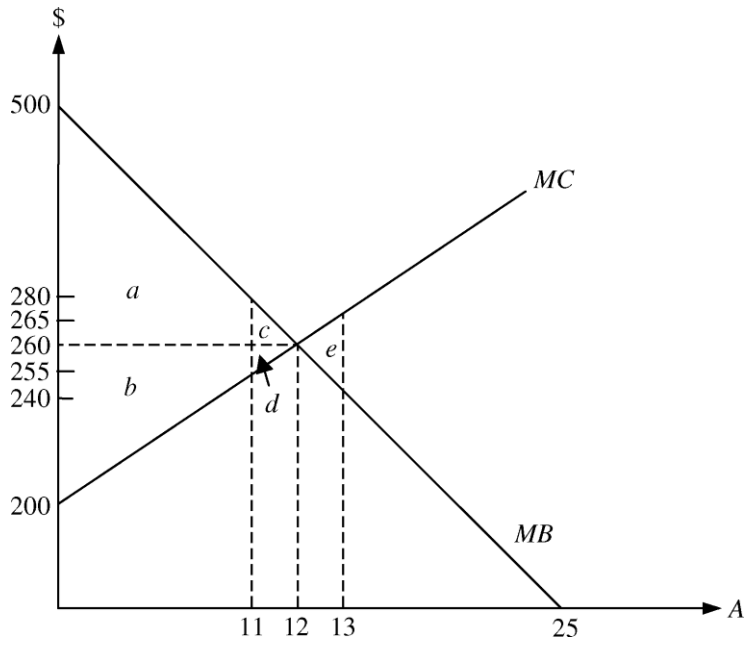
If you abate one million tons too many, the net social benefit is area $a + b + c + d - e$, or

$$1800 - 0.5(265 - 240)(1) = 1800 - 12.5 = \$1787.5 \text{ million.}$$

If you abate 1 million too few tons, then the net social benefit is area $a + b$ or

$$0.5(500 - 280)(11) + (280 - 255)(11) + 0.5(255 - 200)(11) = \$1787.5 \text{ million.}$$

In either case, then, net social benefit falls by $1800 - 1787.5 = \$12.5$ million.



d. Why is it socially efficient to set marginal benefits equal to marginal costs rather than abating until total benefits equal total costs?

It is socially efficient to set marginal benefit equal to marginal cost rather than total benefit equal to total cost because we want to maximize net benefits, which are total benefits minus total cost. Maximizing total benefits minus total cost means that at the margin, the last unit abated will have an equal cost and benefit. Choosing the point where total benefits are equal to total cost would mean that net benefits equal zero, and would result in too much abatement. This would be analogous to choosing to produce where total revenue was equal to total cost. If total revenue is always equal to total cost by choice, then there will never be any profit. In the case of abatement, the more we abate, the costlier it is. Given that funds tend to be scarce, dollars should be allocated to abatement only so long as the benefit of the last unit of abatement is greater than or equal to the cost of the last unit of abatement.

4. Four firms located at different points on a river dump various quantities of effluent into it. The effluent adversely affects the quality of swimming for homeowners who live downstream. These people can build swimming pools to avoid swimming in the river, and the firms can purchase filters that eliminate harmful chemicals dumped in the river. As a policy advisor for a regional planning organization, how would you compare and contrast the following options for dealing with the harmful effect of the effluent:

a. An equal-rate effluent fee on firms located on the river.

First, one needs to know the value to homeowners of swimming in the river. This information can be difficult to obtain, because homeowners will have an incentive to overstate this value. As an upper bound, if there are no considerations other than swimming, one could use the cost of building swimming pools, either a pool for each homeowner or a public pool for all homeowners. Next, one needs to know the marginal cost of abatement. If the abatement technology is well understood, this information should be readily obtainable. If the abatement technology is not understood, an estimate based on the firms' knowledge must be used.

The choice of a policy tool will depend on the marginal benefits and costs of abatement. If firms are charged an equal-rate effluent fee, the firms will reduce effluent to the point where the marginal cost of abatement is equal to the fee. If this reduction is not high enough to permit swimming, the

fee could be increased. Alternatively, revenue from the fees could be used to provide swimming facilities, reducing the need for effluent reduction. If the fee is set equal to the marginal social cost of the pollution, the efficient level of dumping will result.

b. An equal standard per firm on the level of effluent that each can dump.

An equal standard will be efficient only if all the firms have the same marginal abatement costs and the policy maker has complete information regarding the marginal costs and benefits of abatement, so that the efficient level of the standard can be determined. If the marginal costs of abatement differ across firms, an equal standard will result in some firms reducing their effluent by too much and others by too little. Moreover, the standard will not encourage firms to reduce effluent further if new filtering technologies become available.

c. A transferable effluent permit system in which the aggregate level of effluent is fixed and all firms receive identical permits.

A transferable effluent permit system requires the policy maker to determine the efficient total effluent level. Once the permits are distributed and a market develops, firms with higher abatement costs will purchase permits from firms with lower abatement costs. In this way, the effluent level determined by the policy maker will be achieved efficiently. However, unless permits are sold initially rather than given away, no revenue will be generated for the regional organization.

5. Medical research has shown the negative health effects of "secondhand" smoke. Recent social trends point to growing intolerance of smoking in public areas. If you are a smoker and you wish to continue smoking despite tougher anti smoking laws, describe the effect of the following legislative proposals on your behavior. As a result of these programs, do you, the individual smoker, benefit? Does society benefit as a whole?

Since smoking in public areas is similar to polluting the air, the programs proposed here are similar to those examined for air pollution. A bill to lower tar and nicotine levels is similar to an emissions standard, and a tax on cigarettes is similar to an emissions fee. Requiring a smoking permit is similar to a system of emissions permits, assuming that the permits would not be transferable. The individual smoker in all of these programs is being forced to internalize the externality of "secondhand" smoke and will be worse off. Society will be better off if the benefits of a particular proposal outweigh the cost of implementing that proposal. Unfortunately, the benefits of reducing secondhand smoke are uncertain, and assessing those benefits is costly.

a. A bill is proposed that would lower tar and nicotine levels in all cigarettes.

Some smokers might actually smoke more in an effort to maintain a constant level of consumption of nicotine, although the total amount of tar and nicotine released into the air would probably be reduced. The smoker is worse off because he or she will spend more on cigarettes and consume less tar and nicotine. Nonsmokers would be better off because less tar and nicotine would be in the air. It is difficult to know whether society as a whole would be better or worse off.

b. A tax is levied on each pack of cigarettes.

Producers will pay some of the tax and consumers (i.e., smokers) will also pay a portion. Thus the price of cigarettes will increase, and smokers will smoke fewer cigarettes. The extent of the effect of the tax depends on the elasticity of demand for cigarettes. Nonsmokers would be better off because there is less smoking but smokers are worse off, so it is unclear whether society as a whole benefits. Also, some smokers might substitute cigars or pipes for cigarettes, which might actually be worse for nonsmokers.

c. A tax is levied on each pack of cigarettes sold.

It does not matter upon whom the tax is levied, it will be shared between consumers and producers in exactly the same proportions as in part b, so the effects will be the same as in part b.

d. Smokers would be required to carry government-issued smoking permits at all times.

Smoking permits effectively transfer property rights to clean air from smokers to nonsmokers. A major issue with this program would be the high cost of enforcing the permits. The price of the permit would induce some smokers to quit smoking, but it would not raise the marginal cost of smoking. Therefore smokers who bought permits would continue to smoke about the same amount. Again, smokers would be worse off and nonsmokers better off, so it is unclear whether society benefits as a whole.

6. The market for paper in a particular region in the United States is characterized by the following demand and supply curves

$$Q_D = 160{,}000 ? \quad 000P \quad \text{and} \quad Q_S = 40{,}000 + 2000P,$$

where Q_D is the quantity demanded in 100-pound lots, Q_S is the quantity supplied in 100-pound lots, and P is the price per 100-pound lot. Currently there is no attempt to regulate the dumping of effluent into streams and rivers by the paper mills. As a result, dumping is widespread. The marginal external cost (*MEC*) associated with the production of paper is given by the curve $MEC = 0.0006Q_S$.

a. Calculate the output and price of paper if it is produced under competitive conditions and no attempt is made to monitor or regulate the dumping of effluent.

The equilibrium price and output would be where quantity demanded is equal to quantity supplied:

$$160{,}000 - 2000P = 40{,}000 + 2000P$$

$$4000P = 120{,}000$$

P = \$30 per 100-pound lot, and

Q = 100,000 lots.

b. Determine the socially efficient price and output of paper.

To find the socially efficient solution, we need to consider the external costs, as given by $MEC = 0.0006Q_S$, as well as the private costs, as given by $Q_S = 40{,}000 + 2000P$. Rewriting the supply curve, the private costs are $P = 0.0005Q_S - 20 = MC$. Therefore,

$$MSC = MC + MEC = 0.0005Q_S - 20 + 0.0006Q_S$$

$$MSC = 0.0011Q_S - 20.$$

Solve the demand curve for price: $P = 80 - 0.0005Q$. This is the marginal benefit curve. Setting marginal social cost equal to marginal benefit,

$$0.0011Q - 20 = 80 - 0.0005Q$$

Q = 62,500 lots, and

P = \$48.75 per lot.

c. Explain why the answers you calculated in parts a and b differ.

The equilibrium quantity declined and the equilibrium price rose in part b because the external costs were considered. Ignoring the external costs of paper production results in too much paper being produced and sold at too low a price.

7. In a market for dry cleaning, the inverse market demand function is given by $P = 100 - Q$ and the (private) marginal cost of production for the aggregation of all dry-cleaning firms is given by $MC = 10 + Q$. Finally, the pollution generated by the dry-cleaning process creates external damages given by the marginal external cost curve $MEC = Q$.

a. Calculate the output and price of dry cleaning if it is produced under competitive conditions without regulation.

Set demand equal to supply to find the competitive equilibrium. To do this, set price equal to marginal cost (which is the industry supply function):

$$100 - Q = 10 + Q, \text{ so}$$
$$Q = 45, \text{ and } P = \$55.$$

b. Determine the socially efficient price and output of dry cleaning.

First, calculate the marginal social cost (*MSC*), which is equal to the marginal external cost plus the private marginal cost. Next, set *MSC* equal to the market demand function to solve for price and quantity. When all costs are included, the quantity produced will fall and the price will rise:

$$MSC = MC + MEC = (10 + Q) + Q = 10 + 2Q.$$
$$\text{Setting } MSC = MSB\text{: } 10 + 2Q = 100 - Q, \text{ so}$$
$$Q = 30, \text{ and } P = \$70.$$

c. Determine the tax that would result in a competitive market producing the socially efficient output.

If there is a unit tax, t, then the new marginal private cost function is $MC' = (10 + Q) + tQ$. If we now set this new marginal cost function equal to the efficient price of \$70 and substitute 30 for the quantity, we can solve for t:

$$10 + Q + tQ = 70$$
$$30(1 + t) = 60$$
$$1 + t = 2, \text{ and therefore } t = \$1.$$

The tax should be \$1 per unit of output. Note that with $t = 1$, the new private cost function, $(10 + Q) + Q$, is the same as the marginal social cost function.

d. Calculate the output and price of dry cleaning if it is produced under monopolistic conditions without regulation.

The monopolist will set marginal cost equal to marginal revenue. Recall that the marginal revenue curve has a slope that is twice the slope of the demand curve, so $MR = 100 - 2Q = MC = 10 + Q$. Therefore, $Q = 30$ and $P = \$70$, which are the socially efficient levels.

e. Determine the tax that would result in a monopolistic market producing the socially efficient output.

The tax would be zero since the monopolist already produces the socially efficient output in this case.

f. Assuming that no attempt is made to monitor or regulate the pollution, which market structure yields higher social welfare? Discuss.

In this case it is actually the monopolist that yields the higher level of social welfare compared to the competitive market, because the monopolist's profit maximizing price and quantity are the

same as the socially efficient solution. Since a monopolist produces less output and sets a higher price than the competitive equilibrium, it may end up producing closer to the social equilibrium when a negative externality is present.

8. Refer back to Example 18.5 on global warming. Table 18.3 (page 683) shows the annual net benefits from a policy that reduces *GHG* emissions by 1% per year. At what discount rate is the *NPV* of this policy just equal to zero?

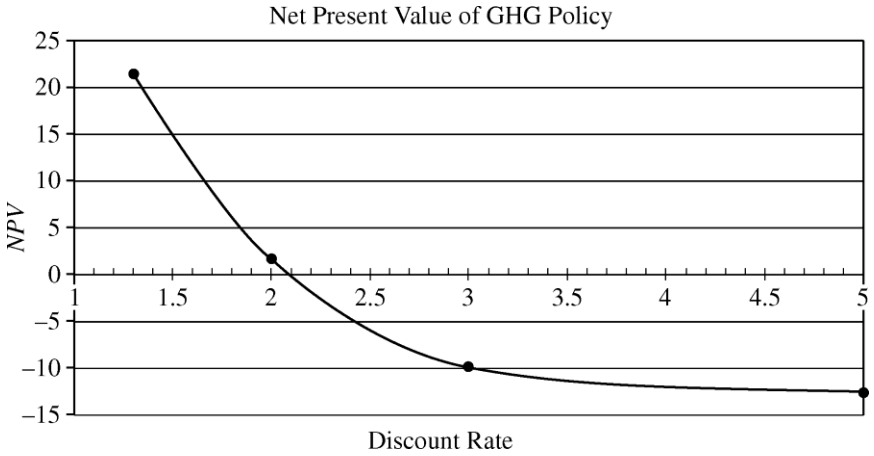
Table 18.3 in the text displays net benefit values at ten-year intervals, so it is not possible to calculate the *NPV* exactly, because the net benefit values change each year. The table below gives the exact net benefit values for each year. Using these numbers, you can compute the *NPV*s given in Example 18.5 and can solve for the discount rate that makes the *NPV* of the policy equal to zero.

Year	Net Benefit	Year	Net Benefit	Year	Net Benefit	Year	Net Benefit
2010	–0.650	2035	–0.813	2060	–1.266	2085	2.139
2011	–0.658	2036	–0.818	2061	–1.199	2086	2.377
2012	–0.665	2037	–0.822	2062	–1.127	2087	2.625
2013	–0.673	2038	–0.825	2063	–1.051	2088	2.884
2014	–0.680	2039	–0.829	2064	–0.970	2089	3.154
2015	–0.688	2040	–0.832	2065	–0.885	2090	3.436
2016	–0.695	2041	–0.834	2066	–0.795	2091	3.730
2017	–0.702	2042	–0.837	2067	–0.700	2092	4.036
2018	–0.710	2043	–0.838	2068	–0.599	2093	4.356
2019	–0.717	2044	–0.840	2069	–0.493	2094	4.689
2020	–0.724	2045	–0.841	2070	–0.382	2095	5.036
2021	–0.731	2046	–0.841	2071	–0.264	2096	5.397
2022	–0.738	2047	–0.841	2072	–0.141	2097	5.774
2023	–0.745	2048	–0.841	2073	–0.011	2098	6.165
2024	–0.751	2049	–0.839	2074	0.126	2099	6.573
2025	–0.758	2050	–0.838	2075	0.269	2100	6.997
2026	–0.764	2051	–0.874	2076	0.420	2101	7.439
2027	–0.770	2052	–0.912	2077	0.578	2102	7.898
2028	–0.777	2053	–0.951	2078	0.743	2103	8.375
2029	–0.782	2054	–0.992	2079	0.916	2104	8.871
2030	–0.788	2055	–1.033	2080	1.098	2105	9.387
2031	–0.794	2056	–1.077	2081	1.288	2106	9.923
2032	–0.799	2057	–1.122	2082	1.487	2107	10.480
2033	–0.804	2058	–1.168	2083	1.695	2108	11.059
2034	–0.809	2059	–1.216	2084	1.912	2109	11.660
						2110	12.284

To find the discount rate that makes $NPV = 0$, set up a spreadsheet with the 101 yearly net benefit values given above. It is easiest to list them in a single column. Make the next column a time variable that starts with a value of zero in 2010 and increases by one each year. The time variable will be 100 in year 2110. Next, choose a cell in your spreadsheet where you list the discount rate, say .013 (i.e., 1.3%). Then, in the column next to the time variable, calculate the present discounted value of each net benefit amount. Do this by writing a formula that references the discount rate that you listed in the separate cell. This way, you will be able to change the discount rate in one cell and all the *PDV* values will change to reflect the new discount rate. Finally, add all the discounted net benefits together to find the *NPV*. If you do this correctly, you will have a $NPV = \$21.3$ trillion when the discount rate is .013. Now try different discount rates until you get an *NPV* of approximately zero. You should find that the discount rate is about .0209, i.e., 2.09%. If you know how to use the solver add-in in Excel, you can use it to find the exact discount rate that makes the *NPV* zero.

If you do not use the exact net benefit values in the table above, there are two other ways to proceed that will give reasonable approximations. First, you could take the net benefit values given in the text and interpolate values for the missing years. Using linear interpolation, you will find a $NPV = 23.0$ when the discount rate equals .013. Using these net benefit values, the discount rate that makes the *NPV* equal zero is .0214, or 2.14%.

Finally, rather than doing any *NPV* calculations, you could simply plot the four different combinations of discount rate and *NPV* values given in the text. Draw a smooth curve through these four points to find the approximate discount rate that drives *NPV* to zero. From the graph below, you can see that it is just shy of 2.1%.



9. A beekeeper lives adjacent to an apple orchard. The orchard owner benefits from the bees because each hive pollinates about one acre of apple trees. The orchard owner pays nothing for this service, however, because the bees come to the orchard without his having to do anything. Because there are not enough bees to pollinate the entire orchard, the orchard owner must complete the pollination by artificial means, at a cost of \$10 per acre of trees.

Beekeeping has a marginal cost $MC = 10 + 5Q$, where Q is the number of beehives. Each hive yields \$40 worth of honey.

a. How many beehives will the beekeeper maintain?

The beekeeper maintains the number of hives that maximizes profits when marginal revenue is equal to marginal cost. With a constant marginal revenue of \$40 (there is no information that would lead us to believe that the beekeeper has any market power) and a marginal cost of $10 + 5Q$:

$$40 = 10 + 5Q, \text{ or } Q = 6.$$

b. Is this the economically efficient number of hives?

If there are too few bees to pollinate the orchard, the farmer must pay \$10 per acre for artificial pollination. Thus the farmer would be willing to pay up to \$10 to the beekeeper to maintain each additional hive. So the marginal social benefit, *MSB*, of each additional hive is \$50, which is greater than the marginal private benefit of \$40. Assuming that the private marginal cost is equal to the social marginal cost, we set $MSB = MC$ to determine the efficient number of hives:

$$50 = 10 + 5Q, \text{ or } Q = 8.$$

Therefore the beekeeper's private choice of $Q = 6$ is not the socially efficient number of hives.

c. What changes would lead to a more efficient operation?

The most radical change that would lead to more efficient operations would be the merger of the farmer's business with the beekeeper's business. This merger would internalize the positive externality of bee pollination. Short of a merger, the farmer and beekeeper should enter into a contract for pollination services, with the farmer paying \$10 per hive to the beekeeper.

10. There are three groups in a community. Their demand curves for public television in hours of programming, *T*, are given respectively by

$$W_1 = \$200 - T,$$

$$W_2 = \$240 - 2T,$$

$$W_3 = \$320 - 2T.$$

Suppose public television is a pure public good that can be produced at a constant marginal cost of \$200 per hour.

a. What is the efficient number of hours of public television?

The efficient number of hours is the amount *T* such that the sum of the marginal benefits is equal to marginal cost. The demand curves represent the marginal benefits (i.e., willingness to pay) for each group. Therefore, add the demand curves vertically to determine the sum of all marginal benefits: $MSB = W_1 + W_2 + W_3 = 760 - 5T$. Setting this equal to *MC*, $760 - 5T = 200$, so $T = 112$.

You can also see from the table below that $MSB = MC = 200$ at $T = 112$ hours of programming.

	Willingness to Pay			
Hours (*T*)	**Group 1 (W_1)**	**Group 2 (W_2)**	**Group 3 (W_3)**	**Vertical Sum**
100	100	40	120	260
106	94	28	108	230
112	88	16	96	200
118	82	4	84	170

b. How much public television would a competitive private market provide?

Assume that public TV is not a public good, and that it costs \$200 to produce each hour of programming for each group. To find the number of hours that the private market would provide, add the individual demand curves horizontally. The efficient number of hours is such that the

private marginal cost of \$200 is equal to the private marginal benefit for each group. Therefore, price will equal marginal cost of \$200. At a price of \$200, group 1 demands no hours, group 2 demands 20 hours, and group 3 demands 60 hours. So a competitive market would provide 80 hours of programming.

11. Reconsider the common resource problem given in Example 18.7. Suppose that crawfish popularity continues to increase, and that the demand curve shifts from $C = 0.401 - 0.0064F$ to $C = 0.50 - 0.0064F$. How does this shift in demand affect the actual crawfish catch, the efficient catch, and the social cost of common access? (*Hint*: Use the marginal social cost and private cost curves given in the example.)

The relevant information is now the following:

Demand: $C = 0.50 - 0.0064F$

MSC: $C = -5.645 + 0.6509F$.

MPC: $C = -0.357 + 0.0573F$

With an increase in demand, the demand curve for crawfish shifts upward, intersecting the price axis at \$0.50. The private cost curve has a positive slope, so additional effort must be made to increase the catch. Since the social cost curve has a positive slope, the socially efficient catch also increases. Determine the socially efficient catch by setting demand equal to *MSC*:

$$0.50 - 0.0064F = -5.645 + 0.6509F, \text{ or } F^* = 9.35.$$

To determine the price that consumers are willing to pay for this quantity, substitute F^* into the demand equation and solve for C:

$$C = 0.50 - 0.0064(9.35), \text{ or } C = \$0.44.$$

To find the actual crawfish catch, set demand equal to the private marginal cost:

$$0.50 - 0.0064F = -0.357 + 0.0573F, \text{ or } F^{**} = 13.45.$$

To determine the price that consumers are willing to pay for this quantity, substitute F^{**} into the demand equation and solve for C:

$$C = 0.50 - 0.0064(13.45), \text{ or } C = \$0.41.$$

Notice that the marginal social cost of producing 13.45 units is

$$MSC = -5.645 + 0.6509(13.45) = \$3.11.$$

With the increase in demand, the social cost of common access is the area of a triangle with a base of 4.1 million pounds (13.45 − 9.35) and a height of \$2.70 (\$3.11 − 0.41), or $0.5 \times 4.1 \times 2.70 = 5.535$, or \$5,535,000. This is \$3,139,000 more than the social cost of common access with the original demand (which was calculated to be \$2,396,000 in Example 18.7).

12. Georges Bank, a highly productive fishing area off New England, can be divided into two zones in terms of fish population. Zone 1 has the higher population per square mile but is subject to severe diminishing returns to fishing effort. The daily fish catch (in tons) in Zone 1 is

$$F_1 = 200(X_1) - 2(X_1)^2$$

where X_1 is the number of boats fishing there. Zone 2 has fewer fish per mile but is larger, and diminishing returns are less of a problem. Its daily fish catch is

$$F_2 = 100(X_2) - (X_2)^2$$

where X_2 is the number of boats fishing in Zone 2. The marginal fish catch *MFC* in each zone can be represented as

$$MFC_1 = 200 - 4(X_1) \text{ and } MFC_2 = 100 - 2(X_2).$$

There are 100 boats now licensed by the U.S. government to fish in these two zones. The fish are sold at $100 per ton. Total cost (capital and operating) per boat is constant at $1000 per day. Answer the following questions about this situation:

a. If the boats are allowed to fish where they want, with no government restriction, how many will fish in each zone? What will be the gross value of the catch?

Without restrictions, the boats will divide themselves so that the average catch (AF_1 and AF_2) for each boat is equal in each zone. (If the average catch in one zone is greater than in the other, boats will leave the zone with the lower catch for the zone with the higher catch.) Solve the following set of equations:

$$AF_1 = AF_2 \text{ and } X_1 + X_2 = 100, \text{ where}$$

$$AF_1 = \frac{200X_1 - 2X_1^2}{X_1} = 200 - 2X_1, \text{ and}$$

$$AF_2 = \frac{100X_2 - X_2^2}{X_2} = 100 - X_2.$$

Therefore, $AF_1 = AF_2$ implies

$$200 - 2X_1 = 100 - X_2,$$

$$200 - 2(100 - X_2) = 100 - X_2, \text{ or } X_2 = \frac{100}{3} \text{ and}$$

$$X_1 = 100 - \left(\frac{100}{3}\right) = \frac{200}{3}.$$

Find the gross catch by substituting the values of X_1 and X_2 into the catch equations:

$$F_1 = (200)\left(\frac{200}{3}\right) - (2)\left(\frac{200}{3}\right)^2 = 13{,}333 - 8889 = 4444, \text{ and}$$

$$F_2 = (100)\left(\frac{100}{3}\right) - \left(\frac{100}{3}\right)^2 = 3333 - 1111 = 2222.$$

The total catch is $F_1 + F_2 = 6666$. At the price of $100 per ton, the value of the catch is $666,600. The average catch for each of the 100 boats in the fishing fleet is 66.66 tons.

To determine the profit per boat, subtract total cost from total revenue:

$$\pi = (100)(66.66) - 1000, \text{ or } \pi = \$5666.$$

Total profit for the fleet is $566,600.

b. If the U.S. government can restrict the number and distribution of the boats, how many should be allocated to each zone? What will be the gross value of the catch? Assume the total number of boats remains at 100.

Assume that the government wishes to maximize the net social value of the fish catch, i.e., the difference between the total social benefit and the total social cost. The government equates the marginal fish catch in both zones, subject to the restriction that the number of boats equals 100:

$$MFC_1 = MFC_2 \text{ and } X_1 + X_2 = 100,$$

Setting $MFC_1 = MFC_2$ implies:

$$200 - 4X_1 = 100 - 2X_2, \text{ or } 200 - 4(100 - X_2) = 100 - 2X_2, \text{ so } X_2 = 50 \text{ and}$$

$$X_1 = 100 - 50 = 50.$$

Find the gross catch by substituting X_1 and X_2 into the catch equations:

$$F_1 = (200)(50) - (2)(50^2) = 10{,}000 - 5000 = 5000 \text{ and}$$

$$F_2 = (100)(50) - 50^2 = 5000 - 2500 = 2500.$$

The total catch is equal to $F_1 + F_2 = 7500$. At the market price of \$100 per ton, the value of the catch is \$750,000. Total profit is \$650,000. Notice that the profits are not evenly divided between boats in the two zones. The average catch in Zone 1 is 100 tons per boat, while the average catch in Zone 2 is 50 tons per boat. Therefore, fishing in Zone 1 yields a higher profit for the owner of the boat.

c. If additional fishermen want to buy boats and join the fishing fleet, should a government wishing to maximize the net value of the catch grant them licenses? Why or why not?

To answer this question, first determine the profit-maximizing number of boats in each zone. Profits in Zone 1 are

$$\pi_1 = 100(200X_1 - 2X_1^2) - 100X_1 \text{ or } \pi_1 = 19{,}000X_1 - 200X_1^2.$$

To determine the optimal number of boats in Zone 1, take the first derivative of the profit function with respect to X_1, set it equal to zero, and solve for X_1:

$$\frac{d\pi_1}{dX_1} = 19{,}000 - 400X_1 = 0, \text{ or } X_1 = 47.5.$$

Substituting X_1 into the profit equation for Zone 1 gives:

$$\pi_1 = 100[200(47.5) - 2(47.5)^2] - 1000(47.5) = \$451{,}250.$$

For Zone 2 follow a similar procedure. Profits in Zone 2 are

$$\pi_2 = 100(100X_2 - X_2^2) - 1000X_2 \text{ or } \pi_2 = 9000X_2 - 100X_2^2.$$

Taking the derivative of the profit function with respect to X_2 gives

$$\frac{d\pi_2}{dX_2} = 9000 - 200X_2 = 0, \text{ or } X_2 = 45.$$

Substituting X_2 into the profit equation for Zone 2 gives:

$$\pi_2 = (100)[100(45) - 45^2) - 1000(45) = \$202{,}500.$$

Total profit from both zones is \$653,750, with 47.5 boats in Zone 1 and 45 boats in Zone 2. Because each additional boat above 92.5 decreases total profit, the government should not grant any more licenses.