CHAPTER 16 ECONOMICS OF THE ENVIRONMENT

As we have discussed at several points in this book, environmental quality is an important component of our well-being. Recent research shows, for example, that higher air pollution levels not only harm human and non-human health but also lower people's overall happiness.[1] Our contextual economics approach recognizes that all economic activity depends on a continual supply of natural resources, as well as ecological functions that break down our wastes and purify our air and water.

Environmental issues are clearly not separate from economics. Climate change, in particular, represents a threat to our economic well-being. The International Monetary Fund notes that climate change "is set to have a significant economic impact on many countries, with a large number of lower income countries being particularly at risk."[2] A 2022 analysis estimates that insufficient action on climate change could lower GDP in the United States by 4 percent by 2070.[3]

Some people see economics as the cause of many of our environmental problems. Global economic growth over the last few centuries has clearly been associated with increasing pollution, deforestation, species extinctions, and other negative impacts. But economics does not necessarily prioritize economic growth over the quality of the environment. Nobel prize–winning economist Paul Krugman has written that:

> economists are on average more pro-environment than other people of similar incomes and backgrounds. Why? Because standard economic theory automatically predisposes those who believe in it to favor strong environmental protection.[4]

In this final chapter, we explore how to use insights from economics to better manage our shared environment. We will find that environmental concerns often present a valid justification for government intervention in markets and that a healthy economy and a healthy environment can coexist. We will discuss the policies that economists have developed to address environmental problems, with a particular focus on climate change. But first, we provide a summary of the current state of the world's environment.

1. OVERVIEW OF GLOBAL ENVIRONMENTAL ISSUES

Debate over the ability of the earth's resources to sustain human populations can be traced back to 1798, when British economist Thomas Malthus wrote *An Essay on the Principle of Population*. Malthus predicted that unchecked human population growth would eventually outpace the growth in agricultural production, leading to widespread food scarcity and a resulting population crash. Malthus's prediction turned out to be inaccurate, as technological advances during the Industrial Revolution increased food production at a greater rate than population growth.

In recent decades, there has been renewed concern of the environmental impacts associated with the growth of the human population and economy. On the positive side, recall from our discussion in Chapter 15 (Figure 15.1) that global food production, economic activity, and energy production have all grown at a faster rate than population. Thus, it is reasonable to state that, on average, people are better fed, wealthier, and have more access to energy than at any time in the past. But in many respects such improvements in living standards have come at a cost of a degraded environment, including deforestation, air and water pollution, depletion of fisheries and water supplies, and climate change. A central challenge of the twenty-first century is to transition to a more sustainable global economy—one that is more reliant on renewable energy, generates less waste, and respects ecological limits. We now turn to a summary of five key environmental issues that will need to be addressed if we are to make significant progress toward sustainability:

1. Global population
2. Nonrenewable resource availability
3. Renewable resources
4. Pollution and wastes
5. Climate change

1.1 GLOBAL POPULATION

Economic and technological growth since the Industrial Revolution has fostered a dramatic increase in world population. In general, as population increases, so do negative environmental impacts. The global population has increased from approximately 1 billion in 1800 to over 8 billion in 2024. According to the United Nations' "medium variant" population projection, global population will increase to about 9.7 billion by 2050 and then peak at 10.4 billion sometime around 2100.[5] The vast majority of population growth is expected to occur in lower-income countries, particularly in Africa.

Successfully predicting long-term population growth has proven to be difficult, as it depends on being able to accurately estimate how factors such as economic growth and women's education will affect fertility and mortality. The U.N. accounts for such uncertainty in their projections, which estimate with 95 percent certainty that the global population in 2100 will be between 8.9 and 12.4 billion. Other demographers believe that the world's population will peak much sooner than 2100, as the U.N. predicts in their medium variant. They argue that the global population will peak around 2060 or 2070, before reaching 10 billion, and then begin to decline.[6] Obviously, humanity's environmental impacts will be quite different in 2100 if there are only, say, 8 billion humans on the planet as opposed to 10−12 billion. Population stabilization is thus an essential aspect of a transition to sustainability. One thing that nearly everyone agrees on is that the most effective way to encourage declines in fertility is to enact policies that increase girls' education. Educated women are more likely to use contraception and desire fewer children because of higher opportunity costs if they leave the workforce to care for children.[7] A 2018 reported sponsored by the World Bank concludes that the global human capital benefits of universal secondary education for girls would be at least $3 trillion per year.[8]

1.2 NONRENEWABLE RESOURCES

Nonrenewable resources are those resources that do not regenerate through natural processes, at least on a human time scale, such as oil, coal, and mineral ores. While the global physical stock of a nonrenewable resource is a fixed quantity, known reserves fluctuate as some resources are extracted while new reserves are discovered. Also, changes in technology and prices can determine whether particular reserves are economically viable to exploit.

nonrenewable resources: resources that do not regenerate through natural processes, at least on a human time scale, such as oil, coal, and mineral ores

Known global reserves of oil have actually been increasing in recent decades. Global reserves of many other important nonrenewable resources, including coal, natural gas, aluminum, copper, and lithium, are also sufficient to meet human needs for the foreseeable future. However, there are concerns about limited supplies of some nonrenewable resources, particularly "rare earth" minerals that are critical for the manufacturing of green technologies such as electric vehicles and wind turbines.[9] Overall, the greatest concern with nonrenewable resources does not seem to be that we will run out in the foreseeable future but the negative environmental consequences of mining, consuming, and disposing of these resources. Policy solutions include increased recycling, effective mining regulations, and transitioning away from fossil fuels in favor of renewable energy.

1.3 RENEWABLE RESOURCES

Renewable resources such as forests, fisheries, freshwater, and soil are regenerated over time through natural and biological processes. If renewable resources are used by humans at rates below the natural rate of regeneration, then sustained availability is possible. Excessive rates of use, however, can lead to depletion or degradation of renewable resources. For example, overfishing can rapidly deplete fish stocks, possibly causing their complete collapse.

renewable resources: resources that are regenerated over a short term through natural and biological processes, such as forests, fisheries, and freshwater

The health of many of the world's renewable resources is declining, including forests, fisheries, freshwater, agricultural soils, and biodiversity. While global deforestation rates have been declining, the world is still losing about 16 million acres of forests each year, shrinking wildlife habitats and contributing to climate change.[10] According to the United Nations, 93 percent of the world's fisheries are considered fully or overly fished, leading to a call for policies such as catch limits and the elimination of harmful fishing subsidies.[11]

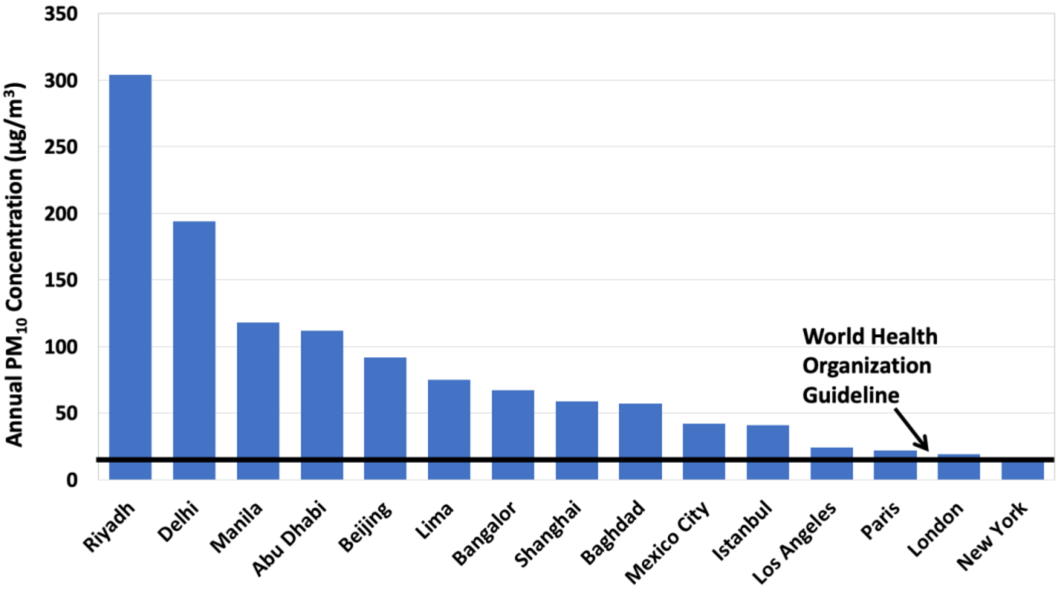
While freshwater is continually renewed through natural processes, only a limited amount is available for human use at any one time. Over 2 billion people live in countries experiencing water scarcity, with water stress expected to increase in the future as a result of climate change.[12] Another water challenge is excessive reliance on groundwater. India in particular is facing severe depletion of groundwater, mainly as a result of electricity subsidies that artificially lower the costs of pumping water.[13]

1.4 POLLUTION AND WASTES

As discussed in Chapter 8, damage from pollution is not reflected in traditional national accounting measures, even though it clearly reduces well-being. A 2022 study estimates that 9 million people globally die annually from pollution, with air pollution responsible for 6.5 million of these deaths.[14] More than 90 percent of the pollution deaths occur in low- and middle-income countries. A 2021 study found that pollution from burning fossil fuels was responsible for one out of 5 deaths globally.[15]

Pollution levels are generally declining in developed countries, producing significant economic benefits. For example, in the United States, aggregate emissions of the most common air pollutants have declined by 78 percent between 1970 and 2022.[16] Meanwhile, air pollution in low- and middle-income countries has typically increased. As we see in Figure 16.1, air pollution levels in major cities in low- and middle-income nations can far exceed the World Health Organization's recommended healthy level of 15 micrograms per cubic meter ($\mu g/m^3$) of particulate matter (PM_{10}), composed of suspended particles of dust, ash, and other harmful material.

Figure 16.1 Average Particulate Matter Concentration, Selected Major Cities



Source: World Health Organization, Ambient Air Quality Database.
Notes: Particulate matter concentrations less than 10 microns. Data year varies by city, generally 2020 or later.

1.5 Climate Change

The vast majority of scientists have concluded that human activity is changing the planet's climate.[17] Emissions of various greenhouse gases, particularly CO_2 and methane from the extraction and burning of fossil fuels, trap heat near the earth's surface, leading not only to a general warming trend but to sea-level rise, ecological disruption, and an increase in severe weather events, such as hurricanes, floods, and droughts.

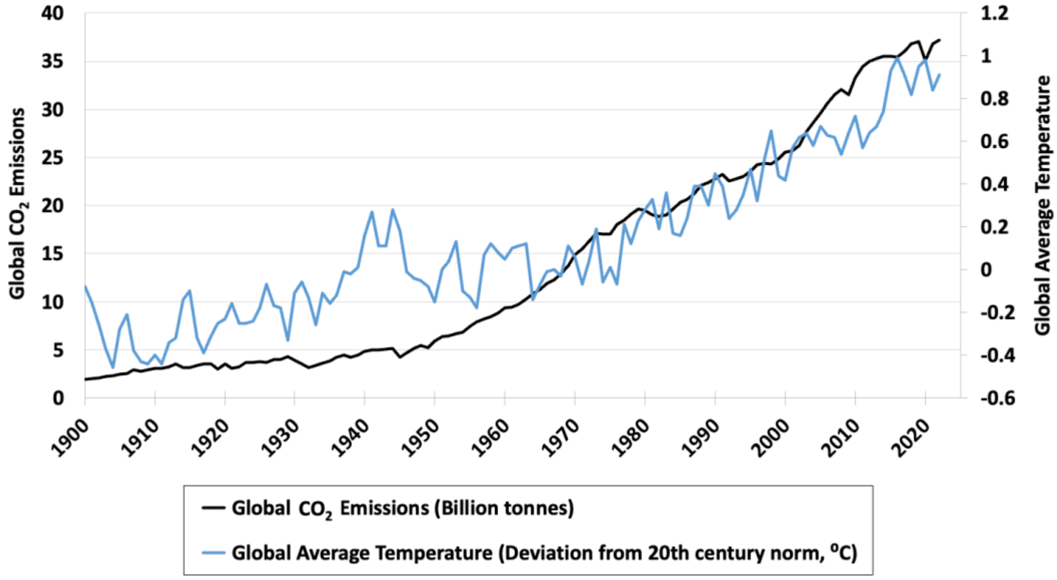
Climate change is already having an impact on all countries, but particularly lower-income countries which tend to lack the resources to adapt to a changing climate. Many developing countries are located in tropical or sub-tropical regions that will see the greatest impacts from extreme weather, rising seas, droughts, and disease spread. The World Bank estimates that declining agricultural yields in Africa related to climate change will increase the number of people in poverty by 43 million by 2030.[18] A 2019 paper finds that climate change is responsible for increased migration, not only directly due to crop failures, water scarcity, and extreme weather, but also indirectly as climate change increases the probability of armed conflicts.[19]

As we see in Figure 16.2, global emissions of carbon dioxide from burning fossil fuels have steadily increased since 1900, especially after 1950. Figure 16.2 also shows the global average temperature, expressed as the deviation from the 20th century average, in degrees Celsius. The global average temperature clearly shows an increasing overall trend since the 1990s.

China is currently the world's top emitter of carbon dioxide, followed by the United States, India, and Russia. While low- and middle-income countries, including China and India, emit more total carbon than the richer OECD nations, emissions per capita are much higher in high-income nations. For example, annual CO_2 emissions per person are about 15 tons in the United States, 8 tons in Germany and China, 2 tons in India, and 0.2 tons in Ethiopia.[20]

At the 2015 international climate meeting in Paris, participating nations set a target of limiting the eventual global temperature increase to no more than 2° Celsius (3.6°F), relative to pre-industrial levels, and to pursue "efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change."[21]

Figure 16.2 Global Carbon Dioxide Emissions from Burning Fossil Fuels and Global Average Temperature, 1900-2022



Sources: Carbon emissions from Global Carbon Project, Global Carbon Budget v.2023; Temperatures from U.S. Environmental Protection Agency, Climate Change Indicators: U.S. and Global Temperature

In order to meet these targets, global emissions of greenhouse gases will need to decline significantly, which will require a transformation of how humans obtain energy. Currently the world economy obtains over 80 percent of its energy from fossil fuels (coal, oil, and natural gas).[22] A comprehensive 2017 analysis concludes that "while social and political barriers exist, converting the world's energy to 100 percent renewable sources by 2050] using existing technologies is technically and economically feasible," which could keep the global temperature within the 1.5°C target set by the UN.[23]

Such a transition will require major policy changes at the national and international level. The 2023 international climate meeting in Dubai, United Arab Emirates, called for a "transition away from fossil fuels" including "a tripling of renewable energy capacity, doubling energy efficiency improvements by 2030, accelerating efforts towards the phase-down of unabated coal power, phasing out inefficient fossil fuel subsidies, and other measures to drive the transition away from fossil fuels in energy systems."[24] We will explore climate change economics and policies in more detail in Section 5.

Discussion Questions

1. Do you think policies are needed to reduce population growth rates? What specific policies, if any, would you recommend? Does your answer differ whether we are considering a low-income or high-income nation?
2. Which resource and environmental problems, other than climate change, do you think are the most pressing? What kinds of policies might be appropriate in responding to these problems?

2. EXTERNALITIES

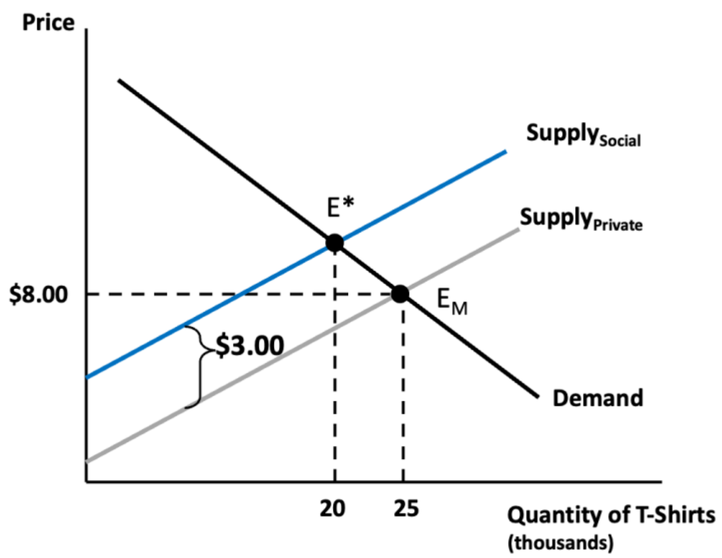
In Chapter 2, we introduced the concept of externalities. Recall that externalities are side effects, positive or negative, of an economic transaction that affect those not directly involved in the transaction.

Pollution is the classic example of a negative externality. When a consumer buys a product, such as a T-shirt, he or she rarely considers the negative environmental impacts associated with its production. T-shirt producers generally do not consider these environmental impacts either. But these impacts clearly do occur, and society as a whole suffers damages from them. The externalities associated with producing T-shirts include the pesticides used to grow the cotton, the chemicals used to dye the shirts, the emissions from the fuels burned to transport the shirts to stores, and other costs.

2.1 NEGATIVE EXTERNALITIES

We can analyze externalities using our standard supply-and-demand graph, as shown in Figure 16.3. In this hypothetical T-shirt market, we assume that neither consumers nor producers consider the negative externalities associated with T-shirts. Thus, the market equilibrium for T-shirts will be determined by the interaction of supply and demand, just as described in Chapter 3. In this market, the equilibrium price of T-shirts is $8, and the quantity sold is 25,000.

Figure 16.3 Analysis of Negative Externality



In order to include externalities in our model, we first need to think a little more deeply about what a supply curve represents. Recall from Chapter 6 that a competitive firm maximizes its profits by producing as long as price is greater than or equal to its marginal production costs. So when we see in Figure 16.3 that firms are willing to supply a total of 25,000 T-shirts at a price of $8, we can conclude that each firm produces T-shirts up to the point where its marginal cost per shirt is $8. In other words, $8 is the highest marginal cost of T-shirts that firms are willing to supply at a price of $8. If the price rises to $8.10 per shirt due to an increase in demand, the quantity supplied would increase, say to 25,100. We can then conclude two things about the marginal cost of producing these 100 additional T-shirts:

1. These additional 100 T-shirts all cost more than $8.00 to produce, because these 100 T-shirts were *not* produced when the price was only $8.00. In other words, these 100 additional T-shirts were not profitable when the price was only $8.00.
2. These additional 100 T-shirts all cost no more than $8.10 to produce, or else they wouldn't be profitable at a price of $8.10.

We can thus conclude that at the higher price of $8.10 per T-shirt, the maximum marginal cost of T-shirts supplied to the market is $8.10. The point on the supply curve where price is $8.10 and quantity is 25,100 is actually telling us something about the marginal cost of production of the additional 100 T-shirts. The important insight here is that points on a supply curve actually represent the marginal cost of the last few units supplied. Or, even more simply, a supply curve is actually a marginal cost curve!

We can now use this insight to incorporate externalities into our model. We label the market supply curve in Figure 16.3 $Supply_{Private}$ because it is based solely on the marginal costs of private suppliers (i.e., T-shirt businesses). As previously stated, private suppliers do not consider externality costs. However, the total social costs of supplying T-shirts not only include the private costs such as labor, materials, and transportation, but also the externality costs. So $Supply_{Private}$ understates the social marginal costs of T-shirt production.

Economists have developed numerous techniques for estimating externality costs in monetary units, using data from market decisions and survey research. While we don't explore these techniques in this book, let's assume that the externality cost per T-shirt is $3. This $3 cost represents the damage from all the environmental impacts of T-shirt production, including pesticide runoff, air pollution, and so on.

The cost to society as a whole for each T-shirt produced is the sum of the private production cost and the external cost of $3. From the social perspective, the supply curve "should" be $Supply_{Social}$, not $Supply_{Private}$. Note that $Supply_{Social}$ is obtained by vertically adding $3 to each point on $Supply_{Private}$. Further, instead of the market equilibrium at E_M with 25,000 T-shirts being sold, the optimal social outcome is actually at E^* with only 20,000 T-shirts being sold. For each T-shirt sold above 20,000, *society is actually becoming worse off*, as the true social marginal costs (along $Supply_{Social}$) exceed the value consumers along the demand curve place on these T-shirts. In the presence of negative externalities, the unregulated market equilibrium will not be the best outcome from a social perspective—it is economically inefficient.

If the unregulated market outcome is inefficient, how can we shift to the optimal social outcome at E^*? Economists tend to favor instituting a tax in a market with negative externalities. A tax that is levied in response to a negative externality is called a **Pigovian tax**, after British economist Arthur Pigou, who proposed the idea in the 1920s.

Pigovian tax: a tax levied on a product to reduce or eliminate the negative externality associated with its production

Suppose that we impose a tax of $3 on each T-shirt, to be paid by producers. This tax increases the marginal cost of supplying each T-shirt by $3. Effectively, the Pigovian tax will shift $Supply_{Private}$ upward by $3 so that it overlaps $Supply_{Social}$. With the tax in place, the equilibrium will shift to E^*—the economically efficient outcome considering society as a whole.

We say that the Pigovian tax has "**internalized the negative externality**," because the external costs of $3 per T-shirt are now integrated into the market. While we indicated that producers initially paid the tax, you might think that the tax will simply be passed on to consumers, who will now pay $11 per shirt. But looking closely at our graph, we can see that only some of the tax has been passed on to consumers. Note that the vertical distance between the two supply curves is always $3. At a quantity of 20,000 shirts, we see that price has increased from $8 by an amount smaller than the vertical distance between the two supply curves. In our example, it appears that about half the tax is passed on as a price increase, so that the price of T-shirts will rise from $8 to about $9.50 as a result of the $3 tax.

internalizing negative externalities: bringing external costs into the market (for example, by instituting a Pigovian tax at a level equal to the externality damage), thus making market participants pay the true social cost of their actions

The extent to which a Pigovian tax is passed on to consumers depends on the elasticity of demand. If demand for a product is relatively elastic, then producers won't be able to pass on much of the tax, because doing so will significantly reduce the quantity demanded. If demand is relatively inelastic, then producers can pass on most of the tax, because consumers won't significantly reduce their quantity demanded as price rises.

Note that a Pigovian tax internalizes, but doesn't eliminate, negative externalities. Externality damages are still $3 per shirt, but the quantity sold is now only 20,000 shirts. Also notice that the government now collects $60,000 in revenues from the tax (20,000 shirts x $3 per shirt). In principle, the government can use this revenue however it wants. Some economists suggest that the tax revenues should be used to lower other taxes, as we'll discuss later in the chapter.

Economists have estimated appropriate Pigovian taxes for various products, particularly gasoline and other fossil fuels. For example, two recent estimates of the Pigovian tax on gasoline in the United States are $1.60 and $3.80 per gallon, meaning that the price of gasoline should approximately double in order for its price to reflect social costs accurately.[25] For more on Pigovian taxes on fossil fuels, see Box 16.1.

BOX 16.1 PIGOVIAN TAXES ON FOSSIL FUELS

A 2014 analysis by the International Monetary Fund estimated the efficient Pigovian taxes on fossil fuels in 156 countries—in other words, the "right" tax that would internalize all negative externalities in each country.[26] Efficient taxes for coal, oil, and natural gas were calculated based on greenhouse gas emissions and local air pollutants. Taxes on motor fuels also included the externalities associated with accidents and road congestion.

The report found that existing energy taxes in many countries "are set at levels that do not reflect environmental damage." The most significant externalities were associated with generating electricity using coal. As burning natural gas emits 40 percent less CO_2 per unit of energy than coal, suggested taxes on natural gas were more modest. For motor fuels, higher taxes were generally warranted due to the impacts of accidents and traffic congestion rather than emissions.

Appropriate Pigovian taxes varied considerably across countries. Recommended gasoline taxes were the equivalent of about $4.30/gallon in Japan, $4.00/gal. in Russia, $2.10/gal. in China, $1.60/gal. in the United States, and $0.80/gal. in Nigeria. The recommended coal tax was about 65 percent higher in China than in Germany due to fewer coal pollution regulations in China. The study found that efficient coal taxes could significantly reduce air pollution deaths in many countries—by 66 percent in China, 63 percent in India, 47 percent in the United States, and 38 percent in the United Kingdom. The report concludes that the results:

suggest large and pervasive disparities between efficient fuel taxes and current practice in developed and developing countries alike, with much (in fact, a huge amount in many countries) at stake for fiscal, environmental, and health outcomes. The main challenge is how to get it done—how to build support for energy price reform.[27]

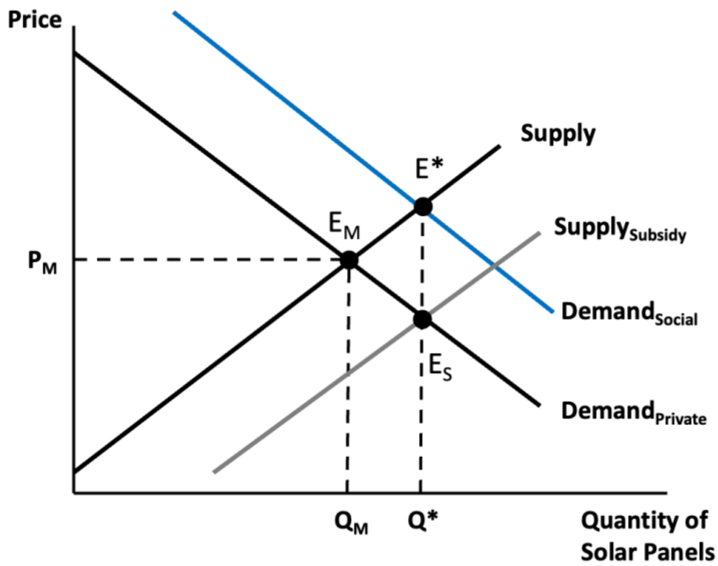
A 2021 report by the World Economic Forum reaffirmed the importance of proper pricing of fossil fuels and reviewed examples of successful implementation at the country level. The authors suggest that the urgency has increased due to recent climate-related disasters such as wildfires and unusually strong hurricanes, and also point out that “a carbon tax policy can raise significant revenue for countries, which can then be used to address the economic harm caused by the burning of fossil fuels”. [28]

2.2 POSITIVE EXTERNALITIES

Externalities can also be positive, meaning that an economic transaction positively affects those outside the market. One example is a homeowner who installs solar panels. Society as a whole benefits, because the solar panels reduce the need for generating electricity from fossil fuels, thus improving air quality and reducing other ecological damages. The homeowner will benefit from reduced costs for electricity (and possibly the ability to sell electricity back to the grid) but in addition there are external benefits to society from reduced pollution.

We present a basic analysis of a positive externality in Figure 16.4. The demand for solar panels by homeowners is $Demand_{Private}$, assuming private consumers don’t consider the social benefits of the panels. The market equilibrium is E_M, which is the normal intersection of supply and demand. The market price of solar panels would be P_M, and the quantity sold would be Q_M.

Figure 16.4 Analysis of a Positive Externality



In addition to the demand for solar panels by homeowners, we need to add the benefits society as a whole receives from each panel. Similar to our addition to the supply curve in the case of a negative externality, with a positive externality we add the social benefit per panel to the demand curve. While the private demand curve represents how much consumers are willing to pay for solar panels, based on the perceived benefits to themselves, we also need to include the benefits to society as whole. This "social" demand curve is $Demand_{Social}$ in Figure 16.4. The social demand curve intersects the supply curve at *E**, resulting in a higher quantity of *Q**. From the social perspective, this is the "correct" or economically efficient level of solar panels.

In the case of a positive externality, the most common policy recommendation is to subsidize the product to encourage greater production. A **subsidy** is a per-unit payment to producers to offset, and thus lower, their production costs. This effectively encourages greater production. We model a subsidy by shifting the supply curve downward, as it lowers the marginal production cost of each panel. With the appropriate subsidy in place, the new supply curve is $Supply_{Subsidy}$, and the new equilibrium point is E_S. The resulting level of solar panel sales, *Q**, is the efficient level from the perspective of social welfare.

subsidy: a per-unit payment to producers to lower production costs and encourage greater production

Discussion Questions

1. What are some of the practical problems of internalizing negative externalities using Pigovian taxes? Can you think of situations where Pigovian taxes might not be the best policy?
2. Consider three different ways a Pigovian tax may be implemented on automobile use: a tax on gasoline, a tax on vehicle purchases, and a per-mile driving charge. Which one do you think would be the best approach for internalizing automobile externalities? Why?

3. MANAGING COMMON PROPERTY RESOURCES AND PUBLIC GOODS

By implementing appropriate taxes and subsidies, governments can increase the social benefits we obtain from goods and services sold in private markets. But when we think about the range of environmental issues, we need to go beyond the regulation of private goods to consider other types of goods, which may require different approaches to internalizing externalities and addressing market failures.

3.1 DEFINING COMMON PROPERTY RESOURCES AND PUBLIC GOODS

Economists classify **private goods** as those that are excludable and rival. An **excludable good** is one whose consumption or use by others can be prevented by its owner. A **rival good** is one whose use by one person reduces the quantity or quality available to others. So your shirt would be considered a private good because, as the owner, you can legally prevent others from using your shirt. A shirt is also rival because two people can't wear the same shirt at the same time.

private good: a good that is excludable and rival
excludable good: a good whose consumption or use by others can be prevented by its owner(s)
rival good: a good whose use by one person reduces the quantity or quality available to others

Many environmental issues involve the management of goods that aren't private goods. Specifically, we will consider **common property resources** and **public goods**. Recall from our discussion in Chapter 2 that public goods are nonexcludable (goods whose benefits are freely available to all) and nonrival (goods whose use by some does not reduce the quantity or quality available to others). National defense is an example of a public good because no one in a country can be excluded from receiving the benefits of national defense, and the fact that I am "using" national defense does not reduce the quantity or quality of national defense available to others. In the environmental area, national parks are an example of public goods (technically a national park can be "excludable" because a fee can be charged for entry, but since these fees are generally low national parks are usually considered to be public goods).

Common property resources are those that are nonexcludable but rival. An unregulated ocean fishery is an example of a common property resource because anyone can access the fishery. Note that a fishery is rival because excessive fishing pressure will lead to a reduction in the fishery stock— thus use by some fishers can reduce the quantity available to others.

public good: a good that is nonexcludable and nonrival
common property resource: a good or service that is nonexcludable and rival

Note that whether something is classified as a common property resource or a public good may depend on how heavily it is being used. A national park that is sparsely visited may be considered a public good if each additional visitor doesn't reduce the quality of the experience for others. But if the park gets quite crowded and each additional visitor reduces the quality of the experience for others, then it would be considered a common property resource.

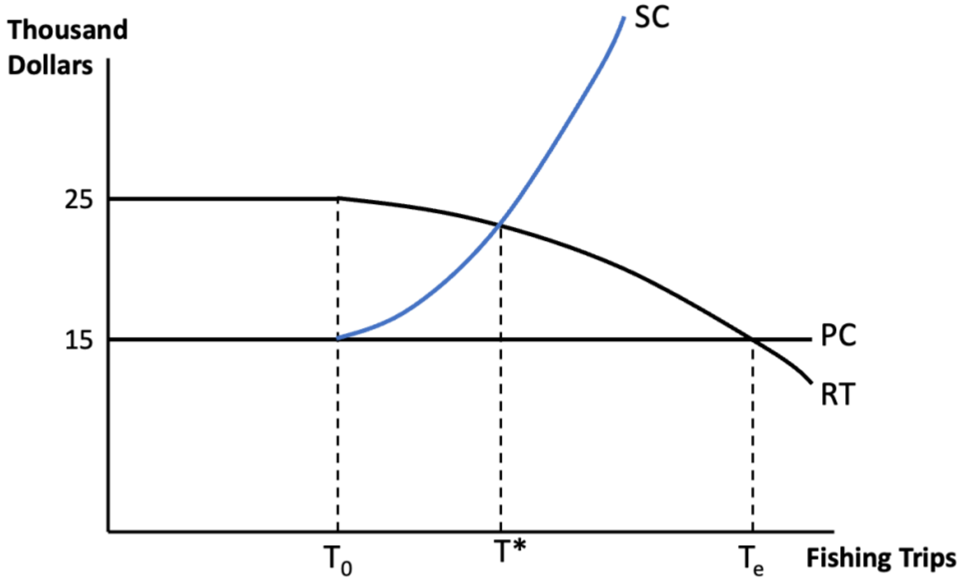
3.2 MANAGEMENT OF COMMON PROPERTY RESOURCES

A common property resource is available to essentially anyone, but it cannot be used or enjoyed by multiple people at the same time, at least with the same level of quality. Overuse is often a problem with a common property resource, as when too many people fish the same fishery, want to play basketball on the same public court, or withdraw groundwater from the same aquifer. We can use tools of economic analysis to examine how this problem arises and what policy solutions may be available.

One way to model a common property resource is to realize that eventually, every user of the resource essentially imposes a cost on other users. In the example of a fishery, if the number of fishing trips is relatively low, adding one more trip is unlikely to affect the catch of other fishers. But above a certain level, each additional fishing trip begins to harm the overall health of the fishery and thus reduce the catch of everyone else in the fishery. Each individual fisher will consider only whether he or she is making a profit. So the fact that others' profits have declined will not be taken into account by additional fishers. This is similar to the idea of a negative externality, but in this case, market participants are harming other market participants.

Figure 16.5 models a fishery as an example of a common property resource. The horizontal axis indicates the number of fishing trips taken in the fishery. Assume that it costs $15,000 to operate a fishing trip, considering labor costs, boat payments, fuel, and other costs. We also include the opportunity cost of fishing as part of the $15,000 total—by taking a fishing trip, one foregoes the opportunity to engage in the next best alternative, such as working a job as a teacher or electrician for a salary. The $15,000 cost represents the private cost of each fishing trip, as shown by the *PC* line in the graph. For simplicity, we assume that the cost to operate a fishing trip is constant, regardless of the number of trips taken.

Figure 16.5 Common Property Model of a Fishery



Next, we need to consider the revenue obtained from each fishing trip. Obviously, this depends on the number of fish caught. For the first few trips, we assume that each fishing trip yields $25,000 in revenues (see curve *RT* in the graph). When we subtract operating costs, each fishing trip results in $10,000 in profits.

Initially, plenty of fish are available for all fishers, so each additional trip does not affect the catch of anyone else. Up to T_0, each fisher is able to obtain revenues of $25,000 per trip and profits of $10,000 per trip. But once the number of trips exceeds T_0, the revenue per trip begins to decline. The fishery is becoming crowded, and because more fishers are competing for limited fish stocks, it becomes more difficult to catch fish. Each fishing trip will still result in a profit, but instead of making a $10,000 profit, the profit per trip will be smaller.

Each fisher will obviously be disappointed to have lower profits. But as long as profits are still positive ($RT > PC$), there is an incentive for more fishers to take trips to the area. In fact, as fishers begin to notice they are catching fewer fish per trip, they may be motivated to increase their fishing efforts in order to catch fish while they still have the opportunity. Note that even if profits per trip are quite small, as we've included opportunity costs in the $15,000 cost per trip, small profits are still better than the value of the next best alternative.

We can model the cost that additional fishers impose on others similarly to how we modeled a negative externality—it represents an additional cost above the private cost of operating a boat trip. Above T_0, each additional trip imposes a social cost as shown by curve SC, equal to the reduction in the profits of *all other fishers*. In other words, *SC* represents the total social cost of operating a boat trip above T_0, considering the private costs of $15,000 plus the external cost equal to the reduction in others' profits.

The socially efficient level of fishing trips is equal to *T**. This is the level at which the profits from a new fishing trip are just enough to compensate for the loss of others' profits. Up to *T**, total profits in the industry are increasing, but above *T**, aggregate profits start to decline.

The problem is that in an unregulated fishery, there is no reason for fishers to stop at *T**. So long as individual fishers can make a profit, the number of fishing trips will continue to increase until we reach T_e. At this point, the economic profit for each fishing trip falls to 0. There will then be no further incentive for additional fishing trips. But at such a high level of fishing effort, the health of the fishery is likely to decline. Over time, the stock of fish may become so depleted that the fishery crashes, leading to collapse of the local fishing industry.

The collapse of a common property resource is often referred to as the "tragedy of the commons."

One solution to the problem of overuse of a common property resource is much like the implementation of a Pigovian tax. We could charge a fee for each fishing trip equal to the external cost imposed on others. If fishers had to pay this fee in addition to their out-of-pocket costs of $15,000, we could adjust the fee until we reached the efficient level of fishing trips, T^*. One problem with this approach is that smaller fishers may be taxed out of the industry, leaving only larger firms that can afford the tax.

Another solution is to institute **individual transferable quotas** (ITQs). With this approach, an organization managing the resource (such as a government agency) sets the total allowable fishing level, such as the number of fishing trips or the total harvest per season. This level of effort is set low enough to maintain the ecological integrity of the resource. The ITQs can be distributed for free or auctioned off to the highest bidders. If they are auctioned, the proceeds can be used by the government to maintain the quality of the resource or as compensation for those who are forced out of the industry. Holders of ITQs may then use them to fish or offer them for sale to interested parties. The price of an ITQ is not set by the government but allowed to vary depending on supply and demand. ITQ programs for ocean fisheries have been established in several countries, including Australia, Canada, Iceland, and the United States. (For more on ITQs, see Box 16.2.)

individual transferable quota (ITQ): tradable rights to access or harvest a common property resource, such as the right to harvest a particular quantity of fish

Box 16.2 Common Property Resource Management in Practice: Individual Transferable Quotas

Iceland has one of the most extensive systems of individual transferable quotas for its marine fisheries. In 1990, Iceland passed the Fisheries Management Act, which established ITQs for all fisheries, with permits allocated to each fishing vessel based on its proportional share of the national catch during a baseline period. Each year, the total allowable catch is determined based on the current scientific evidence regarding the health of each fishery. For example, the allowable cod catch each year is set equal to 20 percent of the "catchable biomass" of the stock. As the health of the cod fishery has improved, the allowable catch has increased—from 130,000 tons in 2007 to about 211,000 tons in 2024 (down from a peak of 268,000 tons in 2020).[29]

The ITQs are fully tradable and even divisible into smaller shares if a fisher wishes to transfer only part of his or her total allocation. Iceland has also implemented regulations that prohibit one company from obtaining an excessive proportion of the permits for a fishery. For example, one company cannot have the rights to more than 12 percent of the national cod allowable catch or 20 percent of the halibut catch. A separate quota system is in place specifically for smaller boats to allow the coexistence of both small- and large-scale fishing operations.[30]

According to Sigurdur Ingi Johannsson, former Prime Minister and Minister for the Environment and Natural Resources, the ITQ system has been very successful, as the approach has both improved the health of Iceland's fisheries and led to an increase in fishery revenues. He said, "We need to use responsible, science-based analysis, but I would say it's a case of so far, so good. Cod, our most valuable fish-stock, is stronger than it has been for 50 years. We are also using fewer vessels, too, which is having less of an environmental impact."[31]

3.3 MANAGEMENT OF PUBLIC GOODS

Public goods are at the opposite end of the spectrum from private goods. For private goods, the ability to charge a price acts as way to exclude nonbuyers. But anyone can enjoy the benefits of a public good without paying, and each additional user does not affect the amount or quality of the good available to others. Hence, we can't rely on private markets to provide the efficient level of public goods. In fact, even though many people value the benefits of public goods, private markets normally fail to provide any public goods at all.

Consider again national defense as an example of a public good. Could we rely on a megacorporation to provide national defense in a market setting? Obviously not. No individual would have an incentive to pay because he or she could receive essentially the same level of benefits without paying. Thus the "equilibrium" quantity of public goods in a market setting is normally zero, as no company would want to produce something for which no one is willing to pay.

Perhaps we could rely on donations to supply public goods. This is done with some public goods, such as public radio and public television. Also, some environmental groups conserve habitats that, while privately owned, can be considered public goods because they are open for public enjoyment. Donations, however, generally are not sufficient for an efficient level of public goods since public goods are nonexcludable—although some people may be willing to donate money to public radio, many others simply listen to it without paying anything. Those who do not pay, but still receive benefits, are called **free riders**.

free riders: those who obtain the benefits of a public good without paying anything for it

Although we cannot rely on private markets or voluntary donations to supply public goods, their adequate supply is of crucial interest to society. One potential source of funding public goods is through taxes collected by the government. Since we all pay taxes, the cost of providing public goods is shared by taxpayers. In democracies, decisions regarding the provision of public goods, such as national defense or environmental public goods, are commonly decided in the political arena rather than in economic markets.

In most countries, elected officials make these decisions for society as a whole. An alternative is to devise a participatory approach where people vote on proposals to increase or decrease the funding for specific projects. For example, town residents may vote on a proposal to increase funding for public schools or parks, which would require higher taxes if approved. Regardless of how the decision is made, some people will surely feel they are paying too much in taxes to support certain public goods, while others may feel that the supply of public goods is insufficient. Debates regarding efficiency and fairness in the case of public goods are inevitably both political and economic in nature.

Discussion Questions

1. Suppose that you are living with three roommates in an apartment with a common area for living, dining, and cooking. Do you think that a "tragedy of the commons" outcome is a likely result without some rules regarding cleaning? What rules would you propose instituting?
2. Consider the provision levels of the following public goods in society: national defense, public education, national parks, environmental quality, public transit, and highways. Do you think that the current "supply" of each of these goods is too high, too low, or about right? What factors do you think determine the amount of resources

that are allocated toward each of these goods? Do policies need to be changed to adjust the allocation?

3. How would individual transferable quotas affect people whose livelihood depends on fishing? Does this seem more or less fair than a fee per fishing trip?

4. ECONOMIC GROWTH AND THE ENVIRONMENT

Economic growth has generally been associated with increasing environmental damage. In this section, we explore the relationship between economic growth and the environment in three ways:

1. How does economic growth tend to affect environmental quality?
2. Does protecting the environment harm employment and economic growth?
3. Is further economic growth compatible with environmental sustainability?

4.1 THE ENVIRONMENTAL KUZNETS CURVE HYPOTHESIS

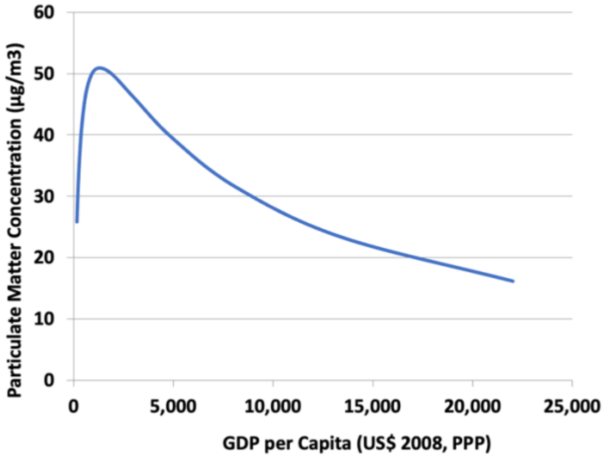
Some researchers have suggested that, in the long run, economic development reduces environmental damages. The logic behind this assertion is that sufficient wealth and technology allow countries to adopt clean production methods and move to a more service-based economy.

The **environmental Kuznets curve (EKC) hypothesis** posits an inverted U-shaped relationship between economic development and environmental damages.[32] The EKC hypothesis states that environmental damage per capita increases in the early stages of economic development, as a country transitions away from an agricultural-based economy to an economy with more manufacturing, energy use, transportation, and so on. Eventually, however, damages reach a maximum and then diminish as a country attains even higher levels of income, allowing it to invest in cleaner production methods. If the evidence supports this hypothesis, it would imply that policies that foster economic growth will eventually promote a cleaner environment as well.

environmental Kuznets curve (EKC) hypothesis: the theory that as a country develops economically environmental damages per capita initially increase, then peak and eventually decrease

The evidence indicates that the EKC relationship does seem to hold for some pollutants. Figure 16.6 shows the findings of a study that estimated the relationship between the average particulate matter (PM_{10}) concentration in a country and a country's per capita income. We see that at very low levels of income, PM_{10} concentration tends to rise quickly as a country develops economically. But the PM_{10} concentration peaks when a country reaches an average income of around $1,300 per person. Air pollution levels then fall steadily with further economic advancement. As noted earlier in the chapter, the World Health Organization has recommended that PM_{10} levels be below 15 μg/m^3. On average, countries achieve this standard when income per person surpasses $20,000. Evidence supporting the EKC hypothesis has also been found for municipal solid waste and other air pollutants such as sulfur dioxide and carbon monoxide.[33]

Figure 16.6 Environmental Kuznets Curve for Particulate Matter



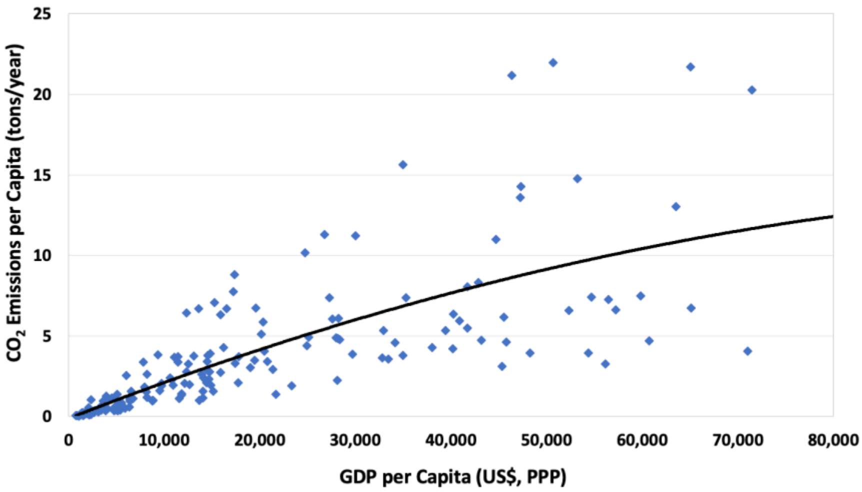
Source: Mazurek, Jiří. 2011. "Environmental Kuznets Curve—A Tie Between Environmental Quality and Economic Prosperity." *Ekonomie a Management*, 14(4):22–31.

The EKC relationship, however, does not appear to hold for several other major environmental problems. Perhaps most importantly, CO_2 emissions show a continuous positive relationship with average income, as shown in Figure 16.7. A simple statistical test to fit an inverted-U curve through the data in Figure 16.7 finds that there is no turning point—per capita CO_2 emissions continue to rise as GDP per capita increases. A more sophisticated analysis in 2015 reached a similar conclusion, that "rising income is associated with an increase in [CO_2] emissions. No income turning points are found for the observed sample of countries." Thus, simply promoting economic growth does not appear to be an effective means to address the issue of global climate change.

The relationship between economic growth and the environment is, in reality, more complex than implied by the EKC hypothesis. As a 2014 paper concludes:

> it would be misleading to follow the policy of polluting first and cleaning later as espoused by proponents of EKC. It does not make much sense to "do nothing" and wait for the magic-wand of economic growth to cure environmental problems. Proactive policies and measures are required to mitigate the problem.[34]

Figure 16.7 Relationship Between Carbon Dioxide Emissions and GDP per Capita, 2020



Source: World Bank, World Development Indicators database.
Notes: Graph excludes four countries with GDP per capita above $80,000 (Qatar, Ireland, Singapore, and Luxembourg). GDP values are adjusted for purchasing power parity.

4.2 DOES PROTECTING THE ENVIRONMENT HARM EMPLOYMENT AND ECONOMIC GROWTH?

Policies that increase environmental protections are sometimes criticized for causing decreases in employment or harming economic growth. What is the evidence on this subject?

Several research studies have explored the relationship between employment and environmental regulation. The overall conclusion is that while increased environmental spending leads to the loss of certain jobs, it creates other jobs. These effects may cancel out or actually result in a net gain of jobs. For example, a 2008 analysis of the U.S. estimated the impact of environmental spending and regulation on employment in various industries and found that:

> contrary to conventional wisdom, [environmental protection (EP)], economic growth, and jobs creation are complementary and compatible: Investments in EP create jobs and displace jobs, but the net effect on employment is positive.[35]

A 2009 review of the literature on the relationship between environmental policies and employment concluded that strong environmental policies will change the distribution of jobs in society but have little effect on the overall level of employment.[36] Focused on Europe, the study found that well-designed environmental policies can sometimes result in net job gains. For example, the additional revenue from higher environmental taxes could be used to reduce the taxes on labor, thus reducing the cost of hiring workers and leading to higher overall employment.

A similar conclusion was reached by a 2016 analysis that estimated the employment impacts of various potential policies to reduce carbon emissions in the United States and found that job losses in "dirty" sectors such as coal mining would be offset by job gains in cleaner sectors such as renewable energy. They concluded that the "overall effects on unemployment should not be a substantial factor in the evaluation of environmental policy" because the net effects are likely to be quite small.[37]

A 2019 analysis estimated the employment impacts of environmental policies to reduce carbon emissions in the United States.[38] The results indicated that overall employment would initially decline but that the long run impact would be negligible as job gains in different sectors offset job losses.

Another criticism of environmental protection is that environmental regulations reduce GDP growth rates. For example, a comprehensive analysis of the Clean Air Act in the United States estimated that economic output in 1990 was about 1 percent lower than it would have been without the policy. The aggregate macroeconomic loss from the Act over the period 1973–1990 was estimated to be about $1 trillion.[39] However, the central estimate of the 1973–1990 benefits was $22 trillion, primarily due to reduced air pollution deaths—indicating a benefit-cost ratio of 22:1. Weighting any economic costs that might result from environmental regulation against the benefits of the regulations, a 2017 OECD report argues that integrating measures to tackle climate change into regular economic policy will have a positive impact on economic growth over the medium and long term.[40]

So while some studies find a slight negative impact of environmental regulation on economic growth as traditionally measured, we need a more complete analysis to determine its overall effect on social well-being. As we saw in Chapter 8, GDP was never intended to measure social well-being, and economists have developed alternative national accounting approaches to supplement or replace GDP. These alternatives offer a more comprehensive framework for fully assessing the impacts of environmental regulations on social well-being.

4.3 ECONOMIC PERSPECTIVES ON THE TRANSITION TO A SUSTAINABLE ECONOMY

Is continued economic growth is compatible with environmental sustainability? Some economists believe that, at least for the foreseeable future, further economic growth is acceptable or desirable as we transition to a more sustainable economy. But others argue that we have already exceeded the planet's carrying capacity, and advocate for a transition to a "no growth" economy, perhaps requiring a period of de-growth during that transition.

The United Nations' Green Economy Initiative, launched in 2008, sees economic growth as compatible with environmental sustainability. The Initiative seeks to promote an economy that "results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities." They propose an annual investment of 2 percent of global GDP over 2010–2050 to fund sustainable technologies and practices, and present a macroeconomic model that estimates the short-term and long-term effects of this investment relative to a business-as-usual (BAU) scenario. Their results found that, while in the first few years the additional investment reduced global GDP/capita by about 1 percent, by 2030 global GDP/capita would be 2 percent higher in the Green Economy scenario relative to BAU. And by 2050, global GDP/capita would be 14 percent higher as a result of sustainable investments.[41]

In addition, the Green Economy scenario resulted in dramatic reductions in predicted environmental impacts. Relative to the BAU scenario, by 2050, global energy demand is reduced by 40 percent, water demand is reduced by 22 percent, total forested land increases by 21 percent, and the global ecological footprint is reduced by 48 percent.

Economist Robert Pollin, in his 2015 book *Greening the Global Economy*, also advocates for an investment of 1.5 percent of global GDP in renewable energy and energy efficiency to fund a transition to a sustainable, low-carbon economy. His analysis concludes that green investments expand employment and economic growth, as jobs in renewable energy and energy efficiency tend to be more labor intensive than jobs in the fossil fuel sector. To assist displaced fossil fuel-industry workers, Pollin proposes job retraining programs and policies promoting full employment.[42]

Analyses such as Pollin's book and the UN's Green Economy Initiative suggest that not only is sustainability compatible with economic growth, green investments can actually *increase* rates of economic growth. But other economists argue that continual economic growth is incompatible with long-term sustainability. Economist Herman Daly noted that continual expansion of the macroeconomy within a finite biosphere is physically impossible. In consequence, Daly advocated for a transition to a **steady-state economy** in which population and the stock of physical capital are held constant.

steady-state economy: an economy that holds constant population and the stock of physical capital

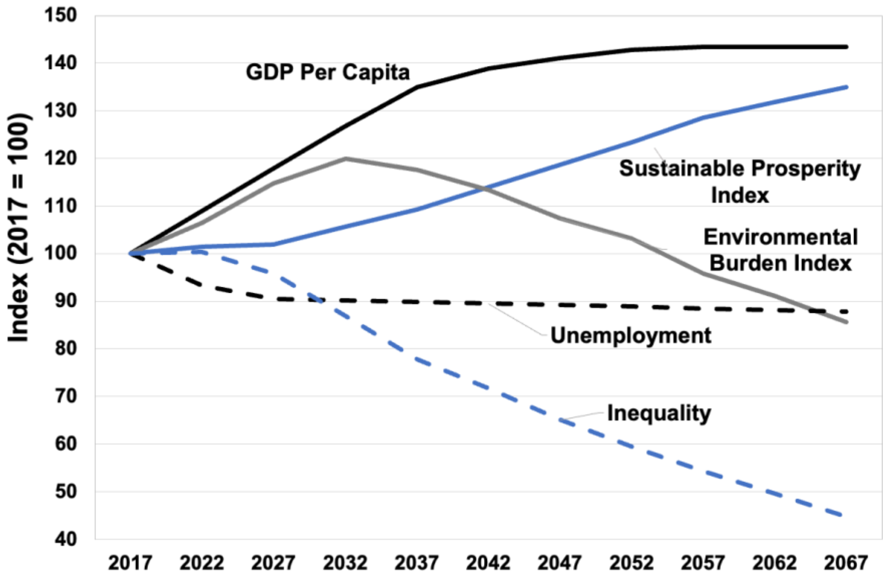
A steady-state economy would not hold human well-being constant, as things such as technology, information, fairness, and wisdom could continue to improve. Also, activities that do not involve resource consumption, and are environmentally neutral or environmentally friendly, could continue to grow. Such activities could include services, arts, communication, and education. Daly distinguished between growth and development—the steady-state economy "develops but does not grow, just as the planet earth, of which it is a subsystem, develops without growing."[43]

A similar viewpoint is espoused in Tim Jackson's book *Prosperity Without Growth*. Jackson calls for an ecological macroeconomics that maintains economic stability without a reliance on traditional growth. He advocates for macroeconomic policies such as public investments in ecological assets and giving workers more choice over their work hours to promote a transition to a sustainable economy.[44]

Economist Peter Victor, in his book *Managing Without Growth: Slower by Design, not Disaster*, has developed a macroeconomic model to explore how a national economy would perform during a transition to a sustainable low- or zero-growth future.[45] Figure 16.8 shows Victor's model applied to the Canadian economy. In this scenario, the Canadian government is assumed to introduce a comprehensive program for lowering greenhouse gas (GHG) emissions by imposing a carbon price on GHG emissions, investing in GHG emissions reduction, and the electrification of road and rail transport. Such measures are predicted to reduce greenhouse gas emissions by 85 percent by the year 2067.

Victor's model for the Canadian economy shows that GDP per capita stabilizes after 2052, and the environmental burden index (which includes variables such as GHG emissions) decreases by 14 percent by the year 2067. Reduced working hours play a key role in preventing increases in unemployment. A range of government policies, including more spending on health care and education, is predicted to reduce the level of inequality by 56 percent. The Sustainable Prosperity Index, combining various economic, environmental, and social variables, is predicted to rise by 35 percent.

Figure 16.8 A No-Growth Scenario for the Canadian Economy



Source: Adapted from Victor, Peter. 2019. *Managing Without Growth: Slower by Design, not Disaster*. Edward Elgar, Northampton, MA.

Discussion Questions

1. What is the principle of the environmental Kuznets curve (EKC)? In what areas does it seem applicable, and in what ways could it be inaccurate or misleading? What are some policy implications that can be drawn from an analysis of the evidence regarding the EKC?

2. The promotion of economic growth is often seen as a major policy goal. What do you think is the feasibility of a model that stresses alternative goals such as ecological sustainability and well-being? How would you compare the Green Economy and steady-state economy concepts?

5. CLIMATE CHANGE: ECONOMICS AND POLICY

Climate change is widely considered our greatest environmental challenge. Further, climate change ties together many of the issues we have discussed in this chapter and throughout the text. Emissions of greenhouse gases are clearly a negative externality—it has been called the "greatest market failure the world has seen."[46] The earth's atmosphere is a global common property resource that is suffering from a tragedy of the commons problem.

Climate change raises important economic and human development questions. Will addressing climate change limit the economic aspirations of developing countries? How should the cost of climate policies be divided among countries with different levels of income? In this section, we explore insights from economics about climate change.

5.1 ECONOMIC ANALYSIS OF CLIMATE CHANGE

Carbon dioxide emissions are clearly a negative externality, and thus the standard economic response is to tax them. This tax, reflecting the current and future environmental damages from emitting CO_2 (normally 1 ton), is referred to as the **social cost of carbon**. As far back as the 1990s, economists have widely recommended instituting carbon pricing as a policy response to climate change.[47] But estimates of the social cost of carbon have varied considerably. A relatively low social cost of carbon would imply a modest policy response to climate change. A high social cost of carbon would mean that climate change demands more aggressive policies.

social cost of carbon: a monetary estimate of the discounted long-term damages from emitting a ton of CO_2 in a given year

In a 2023 paper, William Nordhaus (who received the 2018 Nobel Memorial Prize in economics for his climate change analyses) estimated that the social cost of carbon should start at around \$6/ton of CO_2 in 2022, rising to \$90/ton in 2040 under an "optimal" scenario.[48] Other economists propose that the social cost of carbon should be significantly higher, noting that Nordhaus' recommendations would result in unacceptable warming of nearly 3 degrees Celsius (relative to the pre-industrial average) by 2100.

A 2021 paper co-authored by Nobel-prize winning economist Joseph Stiglitz suggests a social cost of carbon of \$100-\$125/ton.[49] A 2022 article in the journal *Nature* produced a social cost of carbon estimate of \$185/ton, based on recent scientific research regarding the potential damages of climate change.[50] An even higher estimate of \$417/ton comes from a 2018 article in the journal *Nature Climate Change*..[51] What accounts for these differences in the social cost of carbon?

An important factor in calculating the social cost of carbon is how to value future damages. Carbon emitted into the atmosphere persists for many decades, so we need to estimate an economic value for damages that will occur in the future. Economists do this by applying a **discount rate** to any future impact. A discount rate is expressed as a percentage, indicating how much future impacts are reduced for each year into the future that they occur. Future damages can be converted to a "present value" using the formula:

$$PV = \$X / (1+r)^n$$

where $X is the value to be discounted, r is the discount rate expressed as a decimal, and n is the number of years into the future. So, for example, if a damage of $100 million occurs 50 years into the future, using a discount rate of 3 percent, we would value that future damage today at only about $23 million [$100 million/$(1.03)^{50}$]. Thus, in this scenario, economists would recommend not spending more than $23 million today in order to avoid $100 million in damages 50 years from now. Future damages are discounted more the higher the discount rate and the longer the time period.

discount rate: the annual percentage rate at which future impacts are discounted relative to the present

Economists justify discounting for a couple of reasons. First, assuming real rates of economic growth remain positive, future generations will be richer than we are today. So, expressed as a percentage of total income, $100 million in damages in 50 years is not as significant as a $100 million damage today. Second, discounting reflects the general tendency for people to devalue the future relative to today (technically called "pure rate of time preference"). From a policy perspective, discounting means that we place less weight on future generations relative to our present needs.

The discount rate used in an economic analysis of climate change can significantly influence the social cost of carbon and, consequently, the policy recommendations. William Nordhaus recommends a discount rate of around 4 percent, which produces his relatively low current social cost of carbon of $6/ton discussed above. In contrast, the $185/ton social cost of carbon mentioned earlier relies on a discount rate of 2 percent. Prominent climate change economist Nicholas Stern recommends a 1.4 percent discount rate primarily based on an ethical argument—that future generations will clearly not consider themselves any less "valuable" than us today. Economics cannot determine which discount rate is "correct", although a survey of nearly 200 experts on discounting revealed an average preferred rate of 2.25 percent, with two-thirds of respondents preferring a rate from 1 to 3 percent.[52]

From an economic perspective, the costs of action to mitigate the magnitude of climate change, such as investments in renewable energy and energy efficiency, should be weighed against the benefits, measured as the future reduction in damages from severe storms, crop losses, tropical diseases, and other impacts. Various economic analyses have estimated that the additional investment needed to limit warming to no more than 2ºC will cost between 0.4 and 2 percent of world GDP annually.[53]

Nearly all recent analyses conclude that the benefits of strong action to mitigate climate change far exceed these costs. For example, a 2021 analysis by Swiss Re (one of the world's largest insurance companies) estimates that without strong mitigation policies the economic costs from additional climate change would be between 7 and 14 percent of the world economy by 2050.[54] A 2022 study estimates that measures to meet the Paris climate targets will result in a net benefit to the world economy of $43 trillion over 2021-2070, and that "the status quo is the costlier choice."[55]

Similarly, a 2022 paper by the International Monetary Fund concludes that "the costs of action are small relative to the costs of inaction."[56] Finally, a 2023 analysis sponsored by over 100 of the world's central banks found that efforts to reduce global carbon emissions to net zero by 2050 would result in global GDP being 7 percent higher as compared to current policies ("net zero" means that remaining emissions would be fully offset by increased carbon removal from forests, improved agricultural practices, and other actions).[57]

5.2 CLIMATE CHANGE POLICY

Carbon Taxes vs. Cap-and-Trade

As mentioned previously, one economic policy to address climate change is to tax carbon emissions. A carbon tax would charge large emitters of CO_2, such as electricity producers, gasoline refineries, and factories, a per-ton fee, effectively internalizing the externality. The individual emitters would choose their pollution level by comparing the tax against the cost of actions to reduce emissions. As long as it was cheaper to reduce emissions than pay the tax, companies would reduce their emissions. The tax would then, to some extent, get passed on to consumers in terms of higher prices. Revenues raised by such a tax could be used to fund the transition to renewable energy or to lower other taxes.

Note that the extent to which a carbon tax would lower emissions depends on how businesses and households respond to higher prices for products such as gasoline, electricity, and air travel. Thus, predicting how much emissions would decline requires information about the price elasticities of demand for these products. Unfortunately, estimates of elasticity can vary significantly, leading to uncertainty about how much emissions will decline. For example, the U.S. Department of Energy has estimated the elasticity of demand for gasoline to be as low as −0.02,[58] suggesting very little change in quantity demanded with higher gas prices, while other research finds the elasticity to be around −0.30.[59] If a carbon tax ends up not reducing emissions as much as expected, it may need to be significantly adjusted.

The main alternative to a carbon tax is a cap-and-trade approach. With this system, the government requires large CO_2 emitters to obtain permits for each ton they desire to emit, with the government capping total emissions by controlling the number of permits. These permits would either be auctioned to the highest bidders or freely distributed according to some criterion, such as historical emissions. Permits could then be traded among firms, with firms holding unneeded permits offering those for sale to other companies that find they need additional permits, with the permit price fluctuating based on market forces.

Permits would create many of the same incentives as taxes—encouraging businesses and consumers to shift away from fossil fuels, fostering investment in renewable energy, and even raising government revenue if the permits are auctioned. The main advantage of permits is that the government directly controls the overall level of emissions. Another advantage of a cap-and-trade approach is that it avoids using the politically unpopular word "tax," even though the ultimate impact on businesses and consumers is essentially the same. A drawback of cap-and-trade is that the market-determined permit price can vary widely, making long-term investment planning more difficult.

National and Regional Climate Policies

Both carbon taxes and permit systems have been used by a number of countries. Approximately 30 countries have implemented carbon taxes, including Japan, Chile, Colombia, and Switzerland. These taxes, however, are generally too low to fully internalize the externalities associated with greenhouse gas emissions.

For example, Mexico's carbon tax is about $4 per ton of CO_2 while Japan's is only $2.40 per ton—well below the social cost of carbon values discussed earlier.[60]. A minimum national carbon tax has been in place in Canada since 2019, but each province is permitted to design its own pricing system and implement more stringent taxes if desired.

The most extensive permit system is the European Union's Emissions Trading System, which has been in place since 2005. The system covers about 10,000 power stations and manufacturing plants, amounting to nearly half of all greenhouse gas emissions in the EU.[61]

The system also covers air transport and (as of 2024) marine vessels. The price of permits in the EU system has varied significantly, ranging from more than €30/ton to less than €1/ton, depending on economic conditions and the allocation of permits.

California has also instituted a carbon trading system and has partnered with Canadian provinces to expand it. South Korea implemented a cap-and-trade system in 2015, initially freely allocating all permits but gradually increasing the share of permits that are auctioned.[62] In 2017, China initiated a nationwide carbon permit system, effectively doubling the proportion of the world's carbon that is subject to pricing.[63]

International Climate Policy

As climate change is a global problem, international cooperation is critical in mounting an adequate response. The first international treaty to address climate change, the 1997 Kyoto Protocol, specified emissions targets only for richer nations, with penalties planned for those that failed to meet their targets. When the treaty expired in 2012, some countries achieved their targets, while others did not (the United States never ratified the treaty), but no penalties were ever enforced.

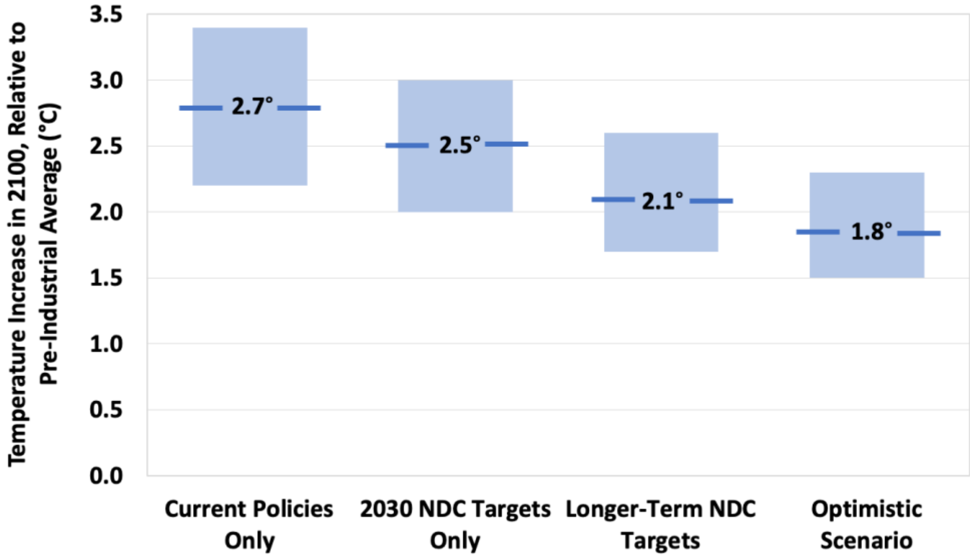
In order to bring nearly all nations into the process, the 2015 Paris Climate Agreement let each country set their own targets on a voluntary basis, referred to as Nationally Determined Contributions (NDCs), without enforceable penalties. It is left to each country to decide what national policies they will enact in order to meet their NDC, whether these policies be taxes, permits, or other regulations. As mentioned earlier, the goal of the Paris Climate Agreement is to limit warming to "well below" an increase of 2°C above pre-industrial levels and to pursue efforts to limit warming further to no more than a 1.5°C increase. Nearly all nations, representing over 98 percent of global carbon emissions, have ratified the Paris Agreement.

Given the voluntary nature of the Paris Climate Agreement, some nations NDCs are more ambitious than others. The organization Climate Action Tracker, which presents independent scientific analysis on climate issues, has rated the NDCs of 39 nations and the European Union.[64] Countries receiving their highest rating ("almost sufficient": compatible with the 2°C target but not the 1.5°C target) include Bhutan, Costa Rica, Ethiopia, and Norway. Countries with "insufficient" NDCs include Brazil, Japan, the EU, and the United States. Eighteen countries have "highly" or "critically insufficient" NDCs, including Canada, China, India, Russia, and Saudi Arabia.

Meeting the more stringent 1.5°C Paris target appears unlikely as this would require approximately halving global carbon emissions by 2030.[65] But meeting the 2°C target is now a distinct possibility, as shown in Figure 16.9. If countries take no further action to reduce emissions, the global average temperature is estimated to be 2.2-3.4°C above pre-industrial levels by 2100, with a median estimate of 2.7°C. If countries only meet their NDC targets for 2030, but then take no further action, the median estimate for warming by 2100 is 2.5°C.

Many countries have already submitted NDCs for further emissions cuts beyond 2030. For example, Norway has pledged to reduce emissions by at least 90 percent by 2050 (relative to 1990 levels). If such countries meet these targets, then the median warming estimate for 2100 is reduced to 2.1°C. Finally, if countries meet their most ambitious long-term targets (for example, the European Union and United States aim to reach net zero emissions by 2050), then median warming falls within the Paris target, at 1.8°C.

Figure 16.9 Projected Global Temperature Increase by 2100, by Scenario



Source: Adapted from Climate Action Tracker, The CAT Thermometer.

As with our discussion of various environmental issues in Section 1 of this chapter, the data on climate change reflect a mixture of good and bad news. The projections in Figure 16.9 assume countries will meet their NDC targets, which may be too optimistic for some nations. On the other hand, under the terms of the Paris Agreement each year nations are urged to submit more ambitious NDCs, which many countries have already done.

The United Nations estimates that global carbon emissions need to fall by 30 percent by 2030 to be compatible with the 2°C target.[66] The International Energy Agency's 2023 *World Energy Outlook* projected that global CO_2 emissions would peak in 2024 or 2025, and thereafter start to decline—but this decline would need to be rapid to meet the Paris target.[67] The 2023 international climate summit in Dubai, UAE, concluded that "implementation of the Paris Agreement is lacking across all areas and not where it should be."[68]

The main reason for optimism about climate change is the dramatically declining cost of renewable energy. The U.S. Department of Energy found that the cost of "utility-scale" solar energy declined by 82 percent from 2010 to 2020,[69] with costs continuing to decline about 10 percent per year.[70] Considering the life-cycle cost of new energy installations without any subsidies, utility-scale solar and wind are currently the two cheapest energy sources globally, on average.[71] Consequently, about 85 percent of new energy installations globally now rely on non-fossil fuel sources, mainly wind and solar.[72] The International Energy Agency concludes that renewables will "dominate the growth of global electricity supply" and, along with nuclear energy, provide over half the world's power generation by 2026.[73] A global transition toward clean energy sources is already well under way, and is expected to gain further momentum, driven by economic logic and policy support.

Discussion Questions

1. What do you think should be done by the United States, China, and other countries in response to global climate change? Can you think of specific policies that would reduce carbon emissions without resulting in significant economic disruption or that might be helpful economically?
2. The 2015 Paris Climate Agreement allows each country to set its own targets on a voluntary basis. We saw above that many country's NDCs are considered insufficient

to meet the Paris targets. What are some of the challenges associated with imposing more strict conditions on all countries? Can you think of ways in which international agreements that require participation by countries facing different kinds of development challenges can be made more effective?

6. POLICIES FOR SUSTAINABLE DEVELOPMENT

Responding to various environmental challenges will require policy changes to foster a more sustainable economy. In this section, we explore some of the environmental policies advocated by economists. But first, we need to define sustainability more precisely.

6.1 DEFINING SUSTAINABILITY

While nearly everyone agrees that we should transition to a more sustainable economy, what exactly does this mean? Economists studying the environment have proposed two definitions of sustainability. One definition, referred to as **weak sustainability**, assumes that natural capital and other types of capital (produced, human, or social) are substitutes. Thus, weak sustainability asserts that natural capital depreciation may be justified as long as it is compensated for with adequate increases in other types of capital. So, for example, the destruction of a wetland in order to construct a new highway could be justified if the economic and social benefits of the highway exceeded the lost ecological value of the wetland.

Strong sustainability takes the perspective that sustainability should be defined solely in terms of natural capital. Under strong sustainability, natural and other types of capital are not substitutes. Strong sustainability doesn't mean that natural capital can never be degraded, but it requires that any degradation of a particular type of natural capital (such as the cutting of a forest for timber) be compensated for with appropriate natural capital restoration (such as replanting trees or restoring a wetland).

weak sustainability: an analytical perspective suggesting that natural capital depreciation is justified as long as it is compensated for with adequate increases in other types of capital
strong sustainability: an analytical perspective suggesting that natural capital depreciation is justified only if it is compensated for with adequate restoration of other natural capital

Strong sustainability isn't necessarily "better" than weak sustainability, but it changes the metrics we would use to determine whether an economy is sustainable. For weak sustainability, we could use a metric such as the Genuine Progress Indicator or the Better Life Index (discussed in Chapter 8), which combine economic, social, and environmental components. The value of these indicators could theoretically increase even if overall environmental quality declines, as long as other components increase sufficiently.

On the other hand, if we wished to pursue strong sustainability, then we would only need to base our analysis on natural capital. We could keep satellite accounts on all important natural capital variables, such as fishery stocks, forest area, greenhouse gas emissions, and mineral reserves. Satellite accounts can be maintained in physical units, such as tons of fish, board-feet of timber, and so on, or in monetary units.

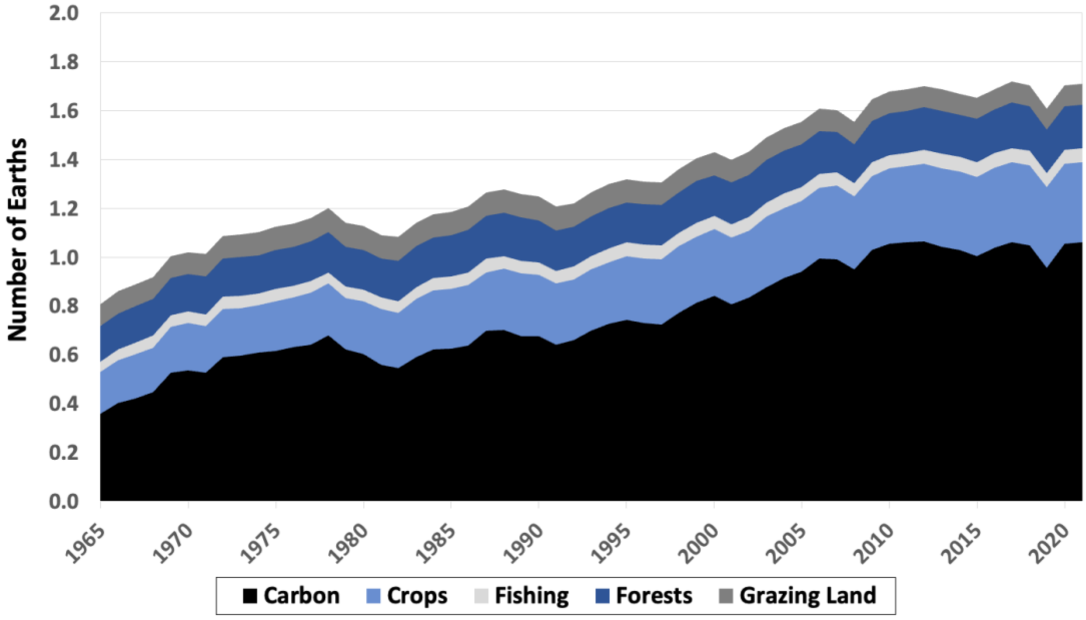
If the accounts are measured in physical units, then comparisons across different categories are difficult. For example, what would we conclude about natural capital overall if we lose 50 acres of wetlands and deplete fish stocks by 100 tons but gain 80 acres of forest? Measuring accounts in monetary units allows for direct comparisons, but converting all variables to monetary units is not straightforward and requires many assumptions. The Sarkozy

Commission (mentioned in Chapter 8) recommended a "dashboard" approach to assessing environmental sustainability, relying on disaggregated physical indicators with a particular emphasis on monitoring variables related to climate change.

The ecological footprint measure, discussed in Chapter 4, provides another perspective on sustainability. Recall that, according to the ecological footprint results, humanity is already in a situation of unsustainable "overshoot." The most recent data suggest that humanity's global environmental impacts are equivalent to using 1.7 earths, considering all the resources we use and the wastes we generate.

Disaggregating the global ecological footprint provides some insight into how we can reach a sustainable level of impacts. In Figure 16.10, we see that about 62 percent of humanity's ecological footprint is attributed to its carbon emissions, resulting in an "earth overshoot" about 65% beyond the planet's capacity. While impacts other than carbon have increased by 48 percent over 1965 to 2022, carbon impacts increased by 226 percent. In order to bring our overall impacts down to a sustainable level, global carbon emissions would need to decline by about two-thirds, which is consistent with the recommendations of the vast majority of climate scientists. Of course, this doesn't necessarily mean we shouldn't reduce other negative impacts, such as deforestation and overfishing. But once again, we can conclude that addressing climate change is our most critical environmental challenge.

Figure 16.10 Global Ecological Footprint, by Impact Type, 1965–2022



Source: Global Footprint Network, Downloadable Ecological Footprint Database

6.2 GREEN TAXES AND SUBSIDY REFORM

As we've already seen, Pigovian taxes are justified by widely accepted economic theory. The policy implications of expanding environmental taxes are extensive. Virtually every product produced in modern markets results in *some* pollution and waste generation. Given that a Pigovian tax increases economic efficiency, should we tax *every* product based on its environmental impacts?

Few economists would support placing an environmental tax on every product. The first reason is that we must consider the administrative costs of collecting Pigovian taxes. For some products with relatively minor environmental impacts, the tax benefits are probably not worth the administrative costs. Second, the task of estimating the environmental damage of *every* product sold, in dollars, is clearly excessive.

Some economists have thus suggested a broad system of **upstream taxes** on the most environmentally damaging products, particularly on fossil fuels (coal, oil, and natural gas), as well as important minerals and key renewable resources. An upstream tax is placed as close as possible to the point where raw materials are extracted. In the case of coal, for example, an upstream tax might be instituted on each ton of coal extracted from coal mines. Upstream taxes on a handful of products are easier to implement than "downstream" taxes on numerous final consumer goods.

Of course, the upstream taxes would ultimately lead to higher prices on final goods, such as gasoline, air travel, and electricity. In many countries, these cost increases would fall most heavily on lower-income people. In order to avoid an overall increase in economic inequality, complementary policies would be needed, such as increased funding for public transportation or direct rebates to lower-income households.

upstream taxes: taxes instituted as close as possible in a production process to the extraction of raw materials

The main barrier to implementing Pigovian taxes is that few politicians are willing to support higher taxes. Environmental taxes, however, could be **revenue neutral** if any tax increases are offset by lowering other taxes or providing rebates so that the effective taxes on an average household remain unchanged. Given that environmental taxes tend to be regressive, revenue neutrality could be achieved by reducing a regressive tax, such as social insurance taxes, or by providing rebates for lower-income households.

revenue-neutral (taxes): offsetting any tax increases with decreases in other taxes or rebates such that overall tax collections remain constant

In addition to higher economic efficiency, a broad shift away from taxes on income and toward taxes on negative externalities provides people with more options to reduce their tax burden. If environmental taxes constitute a large portion of someone's total tax burden, they could reduce this burden by using more efficient vehicles and appliances, relying more on public transportation, reducing energy use, and numerous other options (some of which, however, depend on whether social goods, such as public transportation, are actually available).

We also need to consider how such policies would affect people at different income levels. Higher-income households may be able to afford efficient appliances, electric vehicles, and other environmentally-friendly products. But lower-income households will have fewer options for avoiding the impact of Pigovian taxes. As stated previously, complementary policies, such as rebates, would be necessary to avoid exacerbating existing inequalities.

As we saw earlier in the chapter, subsidies can be used to encourage people to purchase products that generate positive externalities, such as solar panels and electric vehicles. For example, Norway has the most extensive subsidies for electric vehicles. About 84 percent of all new vehicles sold in Norway were pure electric vehicles in 2023, compared about 18 percent of all new vehicles sold globally being battery powered.[74]

Unfortunately, subsidies currently in place in many countries instead *encourage* environmentally damaging behaviors. Agricultural and energy subsidies in most countries encourage the overuse of electricity, gasoline, fertilizer, pesticides, and irrigation water. Reducing or eliminating these subsidies would reduce government expenditures, and the money saved could be used to lower taxes or to promote more sustainable practices. The fossil fuel industry receives the largest share of these perverse subsidies. This mispricing of goods and services effectively permits producers to transfer the costs of environmental damage on to society. (See Box 16.3.)

BOX 16.3 FOSSIL FUEL SUBSIDIES

Fossil fuels are subsidized by governments around the world in numerous explicit and implicit ways. Beyond reducing suppliers' production costs through direct subsidies, implicit subsidies include the failure to institute appropriate Pigovian taxes on fossil fuels for air pollution and climate change damages. According to the International Monetary Fund, global fossil fuel subsidies were $7 trillion in 2022, equal to 7.1 percent of global GDP.[75]

About 60 percent of total subsidies were attributed to a failure to internalize the externalities associated with carbon emissions and local air pollution. The IMF notes that fossil fuel subsidy reforms raising fuel prices to their economically efficient levels would reduce global carbon emissions by 43 percent by 2030—a reduction that is consistent with meeting the Paris Climate Agreement targets of a maximum 1.5-2.0°C temperature increase.

The IMF concludes that subsidy reform would generate an additional $3 trillion in government revenues in low- and middle-income countries. If these revenues are spent appropriately, the additional funds would allow countries to meet the United Nations' Sustainable Development Goals. Despite the potential economic and poverty alleviation benefits, fossil fuel subsidy reforms remain politically challenging, as the IMF notes:

> … many countries have had difficulty reforming subsidies despite the potential gains. When reforms are made, prices increase, and this can lead to social unrest. The absence of public support for subsidy reform is in part due to a lack of confidence in government's ability to compensate the poor and middle class for the higher energy prices they face.

Another factor hampering the reform of inefficient fossil fuel subsidies is the enormous amount of political and financial power harnessed by the companies which benefit from these subsidies. According to a 2023 analysis, the oil and gas industry spent over $2 billion on political activities in the U.S. over 2008-2018, outspending clean energy advocates by a factor of 27.[76]

6.3 GREEN MACROECONOMIC POLICIES

Designing macroeconomic policies that are compatible with sustainability requires some fundamental rethinking about economic goals. The macroeconomic models we developed in earlier chapters have implicitly assumed that more employment, and thus more income, is always better. There is no doubt that employment contributes to people's well-being. People's satisfaction with their jobs is an important predictor of their overall life satisfaction.[77] Full employment is an important economic goal, but people also benefit from time that they spend away from paid employment to do unpaid work, including family care, and to pursue leisure activities.

Several European countries have instituted labor policies that mandate comparatively short working weeks for most employees. Both France and Germany have instituted a standard 35-hour working week. According to one study, policies to reduce annual work hours by just 0.5 percent per year for the remainder of this century could mitigate one-quarter to one-half of future global warming.[78]

As discussed in previous chapters, Keynesian economics focuses on using monetary and fiscal policy to spur aggregate demand during economic downturns. In response to the global financial crisis of 2007–2008 and the recession of 2020, government spending policies were used both to promote economic recovery and to meet environmental objectives such as promoting renewable energy. A "green Keynesian" analysis suggests that instead of just thinking of consumption (C), investment (I), and government spending (G), we can divide each of these terms into environmentally harmful and environmentally positive impacts. Thus, it should be possible to achieve growth in employment and well-being while reducing **throughput**—the flow of inputs into the economy and outputs of wastes and pollution.

throughput: the flow of raw materials and energy through the economy, leading to outputs of waste

As we discussed in Section 4, the extent to which further economic growth, especially associated with high-consumption lifestyles, is compatible with environmental sustainability remains a debated topic. Thus "green growth" policies may be viewed as a transitional phase away from traditional macroeconomic growth toward an ultimate "no growth" or steady-state economy, at least in terms of energy and resource use. Some analysts also promote the concept of a "regenerative economy"—one that actively repairs the damage done by many years of resource-intensive, high-polluting economic production and consumption.

Discussion Questions

1. What specific economic incentives and policies would you recommend for promoting sustainability? Have you heard of any policy examples from the news recently that you think were good ideas?
2. Can you identify areas in which "green Keynesian" economic growth would be desirable and areas in which economic growth is more destructive to the environment? In what ways would a "green" economy look different from our current economy?

7. FINAL THOUGHTS

We started this book by saying that economics is essentially about improving people's well-being. Our contextual approach to economics has recognized that well-being is fundamentally multidimensional. In this book, we have addressed standard economic issues such as markets, consumer and business decisions, economic fluctuations, and global trade. But we have also shown that economic "success" means creating societies that provide fair opportunities for everyone, support quality-of-life goals, and are environmentally sustainable.

In many ways, insights from economics have clearly improved the well-being of billions of people over the last couple of centuries. More people than ever are able to develop their capabilities and achieve a comfortable living standard, although unacceptable levels of inequality, poverty, and discrimination persist.

Society's economic goals are increasingly expanding beyond traditional goals, such as fostering markets and increasing income and employment, toward broader well-being goals such as human empowerment and environmental sustainability. As social goals transform, economics must also adapt and respond.

The idea that economics must evolve as conditions change is not new. During the Great Depression in the 1930s, the famous economist John Maynard Keynes looked into the future and tried to imagine a world of relative affluence, where humanity's true long-term challenge is to learn to live "wisely and agreeably and well." (See Box 16.4.)

BOX 16.4 ECONOMIC POSSIBILITIES FOR OUR GRANDCHILDREN

Looking beyond the dire conditions during the Great Depression, John Maynard Keynes imagined what the world, and economics, might be like 100 years into the future (in 2030).[79] Considering what would be the "economic possibilities for our grandchildren," Keynes's main conclusion was that as people's needs and goals changed with further affluence, so should economics. Writing in 1930, Keynes suggested that:

> a point may soon be reached, much sooner perhaps than we are all of us aware of, when [basic] needs are satisfied in the sense that we prefer to devote our further energies to non-economic purposes. … assuming no important wars and no important increase in population, the economic problem may be solved, or be at least within sight of solution, within a hundred years. This means that the economic problem is not—if we look into the future—the permanent problem of the human race. Thus, for the first time since his creation man will be faced with his real, his permanent problem—how to use his freedom from pressing economic cares, how to occupy the leisure, which science and compound interest will have won for him, to live wisely and agreeably and well.

Keynes recognized that economics has been of critical importance in helping people meet their basic needs. But as people increasingly shift their energies to "non-economic purposes," our views on both policy issues and even morals must also shift. If material consumption needs are largely met, social and environmental goals will become more important. Keynes could not have foreseen the nature of today's climate and environmental crises, but he probably would applaud efforts to shift our focus to efforts towards a more just and sustainable society.

An economy that is stable, equitable, and sustainable is possible. As we have seen throughout this book, economists have developed numerous policy recommendations that can help us achieve our goals. Some of these ideas have been tested and proven effective, some haven't worked as expected, and others remain to be tried. We hope this book has helped you think more deeply about what policies are best in your various roles in life: as a consumer, as an employee or business owner, as a family member, and as a voter. We can't promise that economic decisions are always easy, but we hope the information from this book will help you approach these choices with an informed and open mind.

Discussion Questions

1. How can we reconcile the need for global economic development with the problems of environmental limits? In what ways will established models of economic development have to be modified to deal with new realities?
2. Do you agree with Keynes's belief that industrialized countries can reach a point where needs will be "satisfied in the sense that we prefer to devote our further energies to non-economic purposes"? Do you think that we are any closer to this point than in 1930, when Keynes wrote his essay? Do you see any evidence that this is starting to occur?

REVIEW QUESTIONS

1. What are some major resource and environmental issues for the twenty-first century?
2. How do air pollution levels differ in developed versus developing countries?
3. What temperature targets were set under the 2015 Paris Climate Agreement?
4. What is a negative externality?
5. How can we represent a negative externality in a supply-and-demand graph?
6. What is a Pigovian tax, and why do economists recommend this policy to respond to a negative externality?
7. What is a positive externality, and how can it be represented in a supply-and-demand graph?
8. What policy do economists recommend in the case of a positive externality? Why?
9. What two characteristics define a common property resource?
10. What two characteristics define a public good?
11. Why is an unregulated common property resource likely to be exploited? How can we represent this graphically?
12. How can a common property resource be regulated to achieve the socially efficient outcome?
13. Why are public goods not provided by private markets?
14. What is the environmental Kuznets curve hypothesis? Do the data tend to support it?
15. What is the consensus among economists about the relationship between environmental protection and the economy and jobs?
16. What are the different views among economists regarding the transition to a sustainable economy (i.e., green growth versus no growth)?
17. What is a discount rate? Why is it important in determining the social cost of carbon?
18. What are the advantages and disadvantages of carbon taxes?
19. What are the advantages and disadvantages of a cap-and-trade system to regulate carbon?
20. What are the Paris Climate Agreement goals and are they likely to be achieved?
21. What is the difference between weak and strong sustainability?
22. What are the implications from the data on humanity's ecological footprint?
23. Why do economists tend to prefer Pigovian taxes that are upstream and revenue neutral?
24. What are some green macroeconomic policies?

EXERCISES

1. Issues of environmental sustainability can sometimes be a bit abstract. This exercise is designed to bring them to an individual level. Start at www.footprintnetwork.org/ and familiarize yourself with the notion of "ecological footprints," then take the quiz to discover what your personal footprint looks like. What did you learn that was new information to you? What specifically can you do about this new information?
2. Go to https://data.footprintnetwork.org/ and access data for a number of different countries. For each country, answer the following questions:
   a) What was the per capita ecological footprint of consumption?
   b) What was the per capita biocapacity?
   c) Explain the meaning of the two numbers you just located. What are the implications?

3. Match each concept in Column A with a definition or example in Column B:

Column A	Column B
a. "Green" taxes	1. The perspective that natural capital depreciation should be compensated for with restoration of other natural capital
b. Tradable permit systems	2. An inverted U-shaped relationship between economic development and environmental damages
c. Strong sustainability	3. A situation where population and the use of raw materials and energy have stabilized
d. Throughput	4. Based on the principle that a process of pollution reduction may be most efficiently achieved if businesses have choices
e. Social discount rate	5. Designed to discourage pollution and natural resource depletion by making them more expensive
f. Environmental Kuznets curve	6. Reflects social rather than market valuation of future costs and benefits
g. Steady-state economy	7. The flow of raw materials and energy into the economic system and the flow of wastes from the system

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