23. *Collective Action Problems*

Managing environmental resources sustainably has always been difficult, ever since Homo sapiens *developed modern inventiveness, efficiency, and hunting skills by around 50,000 years ago.*

—Jared Diamond

In this chapter, we cover *collective action problems*: situations in which self-interest does not align with the collective interest. These problems arise in matters small and large. At airports, travelers individually benefit by standing as near as possible to the baggage carousel, but collectively everyone would be better off if people stood back a few feet. In a democracy, people have little incentive to become informed voters given the very low probability of a single vote turning an election, yet a democracy performs better with an informed citizenry. Collective action problems can be thought of as many-player Prisoners' Dilemmas: each person has an incentive to defect, but collectively, everyone does better by cooperating.

People often study collective action models in the context of historical examples such as the management of the Scottish commons or the lobster habitats along the coasts of Newfoundland and Maine.[1] History also contains dramatic failures. Among the most famous is the collapse of the Polynesians on Easter Island, described by Jared Diamond.[2] Easter Island lies over two thousand miles west of Chile in the South Pacific, with no other inhabitable island within a thousand miles in any direction. Given that location, Easter Islanders have always had to manage for themselves. For over a thousand years they lived well. Some estimate that by the early seventeenth century, Easter Island's population exceeded fifteen thousand people. In the sixteenth century, the Easter Islanders marshaled sufficient resources to free up labor to build giant stone heads, called *maoi,* that weigh up to eighty tons. While the Easter Islanders were busy constructing maoi, they were not cooperating in the management of their forests. By 1722, when Europeans first landed on the island, food was relatively scarce and the population had dropped to around two thousand. Few trees over ten feet tall remained. Many species of birds and animals had gone extinct. To use Diamond's phrasing, the civilization collapsed. The collapse became complete when viruses carried by the Europeans killed nearly all of the remaining population.

According to Diamond's account, the collapse of the civilization on Easter Island, as well as the collapses of the Mayans in Central America, the Anasazi in the American Southwest, and the Vinlanders on Greenland, resulted from a combination of overharvesting of natural resources (caused by institutional and cultural failures) and climatic changes. The Vinlanders grazed animals on marginal land and tore up fragile sod to make houses. In short order, the land became barren from overuse, and the Vinlanders starved. Like the Easter Islanders, the Vinlanders had failed to manage a common pool resource. By chopping down too many trees and using up too much turf, they produced a collapse.

Though evocative and compelling, these examples lead many to see collective action problems as something of relevance only in the past. That framing is unfortunate. As the world becomes more interconnected and complex, collective action problems are far more relevant today. We confront collective action problems at almost every scale of human organization. The provision of public education, physical and mental health care, infrastructure, public safety, a justice system, and national defense are all collective action problems, as are managing global fisheries, combating climate change, and in particular reducing the amount of carbon in the atmosphere. In addition, as work becomes more team-based, it necessarily produces collective action problems. Workers have incentives to free ride on the work of others. They also have incentives to overdemand shared workspaces to ensure space for their teams to work.

The chapter is organized as follows: We first define a generic collective action problem, and then analyze three specific types. We start with public goods provision problems, in which individuals contribute money to fund roads, schools, and social services or time and effort to clean a park or watershed. We then study congestion problems, where individuals must restrict use of a resource such as a road system, beach, or park. We finish with renewable resource extraction problems, where individuals consume a resource that can regrow, such as fish, lobster, and trees. Congestion problems reset each day. If too many cars clog London's streets, the city can increase the fee on cars entering the city and solve the problem, and so past overuse has no long-term effects. However, an overharvested forest or fishery takes decades to regrow. We pay consequences for past failures to cooperate.

In each of the three specific models, the nature of the misalignment between individual incentives and collective goals differs, so solutions differ as well. We can solve public goods problems through taxes, and in some cases through sorting. Congestion problems can be solved with fees or usage restrictions. Solving renewable resource problems requires more elaborate monitoring and sanctions as well as conflict resolution mechanisms.

The solutions we offer here provide foundational insights that must be tailored to a local context. Any real-world situation includes layers of complexity that our models leave out. Balinese water temples solve a water allocation problem that is a sequential congestion problem, with upriver people drawing the resource first. International fishing rights that limit access solve a common pool resource problem with a moveable resource, as Norway's solution to coastal fishing could be undermined by overfishing in the nearby waters of Sweden, Russia, and Denmark.[3] Real-world solutions rely in part on the mechanisms discussed in Chapter 22 for building cooperation in the Prisoners' Dilemma: repetition, reputation, network structure, and group selection. Group selection enters indirectly: communities and nations that succeed in solving these problems will thrive, and their successes will be copied by others.

Collective Action Problems

In a *collective action problem*, each person has a choice between contributing and free riding. Free riding is in the individual's best interest. It earns her a higher payoff. Yet when everyone contributes, people receive greater benefits.

A Collective Action Problem

In a **collective action problem**, each of N individuals chooses to free ride (f) or contribute (c) to a collective action. An individual's payoff depends on her own action and the total number of cooperators. Individuals receive a higher payoff from free riding, Payoff(f, C) > Payoff(c, C +1), but the sum of payoffs is maximized when everyone contributes.

A collective action problem can be represented as a many-player version of the Prisoners' Dilemma. We can thus refer back to the solutions proposed in Chapter 22 to get insights into how to create and maintain cooperation. However, those approaches will be incomplete for two reasons: collective action problems involve groups and communities, not just pairs, and many collective action problems take particular forms that make solutions more effective than others.

Public Goods

Our first specific type of collective action problem involves public good provision. Public goods satisfy *non-rivalry* (one person's use in no way interferes with any other person's use) and *non-excludability* (individuals cannot be prevented from use). Public goods include clean air, the national defense, early tornado warning signals, and the production of knowledge. The United States Constitution lists establishing justice, ensuring domestic tranquility, and providing for the common defense as responsibilities of the government. These too are public goods.

Private goods—bicycles, oatmeal cookies, and protractors—are neither non-rival nor non-excludable. Knowledge is both. Juxtaposing an oatmeal cookie and knowledge of trigonometry highlights the difference. A teacher might say, "Carla ate the last oatmeal cookie, so no one else can have one." She would never say, "Melissa, I am so sorry, but Carla just used the Pythagorean theorem, and now no one else can use it."

The non-excludability and non-rivalry of public goods produce a collective action problem not because people do not want to contribute. They do. The problem arises because people undervalue their contributions. For every dollar a person contributes, she adds to everyone's utility. In the formal model we describe here, each person allocates her income between a public good and a representative private good. Think of the private good as money that can be spent on anything else. Extending the model to include multiple public and private goods would only complicate the analysis.

A Public Good Provision Problem

N people each allocate an income $I > N$ between a public good (PUBLIC) and a private good (PRIVATE) that each cost \$1 per unit. Each person has the following utility function:

$$\text{Utility(PUBLIC, PRIVATE)} = 2\sqrt{\text{PUBLIC}} + \text{PRIVATE}$$

Socially optimal allocation: PUBLIC = N (if N = 100, each person contributes \$100).

Equilibrium allocation: PUBLIC = $\frac{1}{N}$ (if N = 100, each person contributes \$0.01).[4]

In the model, we assume that utility is concave in the public good and linear in the private good. Those two assumptions require motivation. Recall that concavity corresponds to diminishing returns: as a person consumes more, she values it less. Concavity in the amount of the public good implies diminishing marginal returns to the public good. This is a standard assumption. People benefit more from adding a third lane to the highway than from adding a fourth lane. People benefit more from cleaning heavily polluted air than from removing the last few particles per billion. We assume linearity in the private good because it represents a composite of all private goods. While utility may be concave in any one good, be it chocolate, televisions, or denim jackets, it is probably closer to linear for all goods. The assumption has the added advantage of making the model easier to analyze.

We first solve for the socially optimal allocation, which we define as the allocation that maximizes the sum of the utilities of the population: the greatest happiness of the greatest number.[5] The socially optimal allocation calls for each individual to allocate \$1 to the public good for each member of the population. Notice that the amount each person contributes to the public good increases with population size. This result does not depend on our particular function. It follows from the fact in a larger population, the non-rival public good can be enjoyed by more people. More people enjoy clean air or national defense, so more should be provided.

The equilibrium contributions equal 1 divided by the population size. As the population increases, people have a greater incentive to free ride off the contributions of others. We can see why by increasing the population size by one. This new person receives the same utility from the public good as everyone else had previously. If other people's contributions stayed the same, this new person has weaker incentives to contribute to the public good than the others had previously. Therefore, he will contribute less than the others contributed. Moreover, whatever amount he does contribute increases the total amount of the public good and creates an incentive for everyone else to contribute less than they had previously.

The model thus reveals that as populations become larger, public good provision problems exacerbate. The optimal level of the good increases, while the incentives to give fall. The formulae for amounts derived in our model (the N and $\frac{1}{N}$) do depend on the functions assumed, but the phenomenon of underprovision holds more generally.

This analysis assumes self-interested people, a common assumption in economic models. Evidence from surveys, experiments, as well as casual observations, reveals that people often have other-regarding preferences. People want good schools and roads for others as well as for themselves. We can include other regarding preferences by adding an *altruism parameter* to our model. A value of zero for that parameter corresponds to the self-interested rational actor from economics, and a value of 1 corresponds to everyone caring as much about others as they care about themselves. As shown in the box, pure altruists, people who care about everyone equally, contribute the socially optimal level. Anything less than pure altruism leads to underprovision.

The calculations show that in large populations, people contribute a portion of the optimal level that is (approximately) equal to the square of the altruism parameter. Though the extent of underprovision depends on the utility function, the example demonstrates the limits of altruism. People who care about others half as much as themselves contribute one-fourth of the optimal level. People who care about others a third as much as themselves contribute a mere one-ninth of the optimal level.

Public Good Provision Among Altruists

N people have altruistic preferences with weight α on aggregate utility:

$$(1-\alpha)\cdot \text{Utility}_j(\text{PUBLIC, PRIVATE}) + \alpha \cdot \sum_{i=1}^{N} \text{Utility}_i(\text{PUBLIC, PRIVATE})$$

Equilibrium pure altruists ($\alpha = 1$): PUBLIC = N

Equilibrium general solution:[6] PUBLIC = $\frac{[(1-\alpha)+\alpha N]^2}{N}$

Example: $\alpha = \frac{1}{2}$: PUBLIC $\approx \frac{N}{4}$

Given that we do not live in a world of pure altruists, we must look to other mechanisms, such as taxation. Governments impose taxes to pay for roads, national defense, education, criminal justice systems, and other public goods. Determining the amount of the tax requires a more elaborate model that includes income and preference heterogeneity. People could vote on an amount and a common tax rate. The spatial voting model predicts a tax rate equal to the preferred level of the public good for the median voter. That level may not be socially optimal if people have heterogeneous incomes and preferences.

Many public goods such as schools, roads, and recycling programs can be classified as *local*. A local community can exclude others, but within the community the public good is non-rival and non-excludable. For local public goods, allowing people to sort into communities based on their preferences, what is called *Tiebout sorting*, offers a possible solution to the public good provision problem. People who want better schools, public parks, pools, and police protection can vote for higher taxes to pay for those public goods. Those people who do not want the local public goods can live in a separate community and pay lower taxes. Tiebout sorting is not a cure-all. It brings attendant costs, including lower social cohesion. Moreover, when high-income people isolate themselves, they reduce public good provision in poorer communities and reduce network interactions that can transfer information and knowledge.[7]

The Congestion Model

In a second type of collective action model, involving resources such as roadways, beaches, and water systems, the value to an individual decreases with the number of users. Anyone who has spent time stuck in traffic has experienced a congestion problem. A wide-open road brings more pleasure and utility than one clogged with cars. Estimates place the costs of traffic delays in the United States in the neighborhood of $100 billion a year. In some cities, notably Los Angeles and Washington, DC, commuters spend, on average, more than sixty hours per year in traffic.

Our *congestion model* assumes a resource of fixed capacity. Each day, people can use the resource or abstain. An individual's benefit from using the resource decreases linearly with the number of other users.[8] The slope of the line, the *congestion parameter*, captures the magnitude of the congestion effect.

A Congestion Model

M of N people choose to use a resource. Their utility can be written as follows:

$$\text{Utility(M)} = B - \theta \cdot M$$

where B denotes the *maximal benefit*, and θ is a *congestion parameter*. The remaining $(N - M)$ people abstain and receive utility of zero.[9]

Socially optimal: $M = \frac{B}{2\theta}$ Utility$(\frac{B}{2}) = \frac{B}{2}$

Nash equilibrium: $M = \frac{B}{\theta}$ Utility$(\frac{B}{\theta}) = 0$

In the socially optimal solution, the number of people who use the resource equals the maximal possible benefit divided by twice the congestion parameter. Those findings align with our intuition. The number of people who use the resource should increase with the maximal benefit and decrease with greater congestion effects. In the Nash equilibrium solution, exactly double the socially optimal number of people use the resource. Congestion becomes so severe that no one receives any benefit. That result is an artifact of the assumption that not using the resource gives a utility of zero. This finding has the counterintuitive implication that a community that builds a beautiful park may not produce much utility for its citizens. In equilibrium, the park will be sufficiently crowded such that being at the park is no more enjoyable than staying home.

When a model produces a result that runs counter to common sense, we need to reason through the result. People must be happier having a park, so the model must be wrong. It is wrong, because we assumed identical preferences. If people vary in how much they enjoy the park, then some people may be receiving positive utility, while others get no benefit. Second, the model assumes the park is always crowded. That will not be true. Third, the alternative option might be going to the beach, not staying home. The new park may make the beach less crowded. Finally, people enjoy diverse experiences. If the city has a skateboard park, a dog park, and a water park, then people may get benefits from the diversity of experience over a period of weeks.

Those challenges notwithstanding, the main result still has some teeth. During busy times, congestion will rise to the point where the park produces no more benefit than any other activity. Crowding will still occur, though not as much as when there was a single park. In addition, as shown in the box below, the creation of multiple parks offers no guarantee that people allocate themselves across those parks optimally. In the example shown in the box on the next page, in equilibrium, too many people go to the larger park.

In addition to creating more parks, a community could try other solutions such as rationing, rotating access, running a lottery, fees, and enlarging capacity. Rationing gives each person or household a fixed amount of the resource. This solution works for divisible resources like water. It is less practical for roads. Rotation schemes divide use of the resource by time. During air pollution alerts, a city can restrict roads to cars with even- (or odd-) numbered license plates on certain days. Other resources, such as placements in popular public schools, cannot be rationed or rotated. In those cases, lotteries can be held.

Multiple Congestible Goods

M people go to Park 1 and $(N - M)$ go to Park 2. To account for Park 2 being larger, utilities are as given below:[10]

Park 1: Utility(M) = $N - M$

Park 2: Utility($N - M$) = $3N - 3 \cdot (N - M)$

Socially optimal: $M = \frac{N}{2}$ creating total utility N^2

Nash equilibrium: $M = \frac{N}{4}$ creating total utility $\frac{9}{16}N^2$

For access to roads, fees are a popular solution. The city of London charges a fee to enter the central city. Limited-access toll roads around the world do the same. Usage fees allocate the resource to those willing to pay the most. These may not be the people who would get the most utility. Singapore uses a combination of fees and limited access. Singapore auctions a fixed number of motor vehicle permits each year. The permits, which last for ten years, often sell for more than the price of a typical car. To reduce congestion during peak times, Singapore, like London, also charges fees for driving into the central business district. Singapore's traffic moves smoothly for a city its size, and the government raises substantial amounts of money, which can then be used for public transportation.

Enlarging the capacity of roads has had mixed success. When a city adds lanes to highways to increase traffic flow, it makes housing near the highways more desirable, a positive feedback. A resulting increase in housing creates more traffic, requiring even wider roads, producing a positive feedback loop similar to those described in the systems dynamic models covered in Chapter 18.

Renewable Resource Extraction

Last, we consider *renewable resource extraction,* in which individuals share a resource that regenerates itself. This model applies to forests, watersheds, grasslands, and fisheries. In each case, the amount of the resource available in the future depends on how much we use now. If too much was used, the resource may not regenerate fast enough. The need for regeneration of the resource makes these problems more fragile than public good problems or congestion problems. A city that underfunds public lighting in one year can increase spending the next year without enduring long term effects from its mistake. If a community overfishes a stream or overharvests a forest, it pays lasting costs because to make fish, you need fish. You do not need streetlights to make streetlights. Furthermore, the renewable resource may be a necessity: food to eat, water to drink, and fuel to keep warm. People need to extract the resource to live.

Renewable Resource Extraction Model

Let $R(t)$ denote the amount of a renewable resource at the start of period t. Let $C(t)$ equal the total amount consumed in period t, and g denote the growth rate of the resource. The amount of the resource in period $t + 1$ is given by the following difference equation: [11]

$$R(t + 1) = (1 + g)[R(t) - C(t)]$$

The *equilibrium consumption level*: $C^* = \frac{g}{(1+g)}R$

Renewable resource extraction problems exhibit a tipping point in the level of consumption. Any rate of consumption above the equilibrium extraction rate will produce a collapse, as can be shown in a formal model. We can think of the amount of the resource as a circular field, a pie. Consumption takes a bite out of that pie. Growth regenerates an amount of resource proportional to the amount remaining. For low levels of consumption, the resource will increase in size. But regrowth will not be able to compensate for high levels of consumption. In between lies an equilibrium level of consumption exactly balanced by regrowth.

If consumption exceeds the equilibrium level, the model predicts accelerating declines that become steep collapses. The slow decline followed by a steep collapse sends a warning for those who manage resources that are difficult to measure accurately, such as fish stocks. Annual catches give a clue, but they are not exact. We should not be surprised that cod fishing in the North Atlantic produced a modern collapse to rival that suffered by the Vinlanders, as described by Jared Diamond in his book on collapsing societies. Cod had been fished in the North Atlantic for over five hundred years. British explorers who first visited the Canadian coast told tales of catching cod in baskets and having difficulty rowing through the prodigious shoals of cod. By 1992, Canada had imposed a moratorium on cod fishing.[12]

Our model of resource extraction assumes a constant growth rate, allowing us to solve for the equilibrium consumption level. In reality, growth rates vary from year to year. In the case of a pasture, growth depends on temperature and rainfall. For a fish population, the growth rate depends on the amount of available food, which in turn depends on variations in weather or on climatic changes.

In the other two models, variation would not have long-term consequences. Some years we might have too much of a public good or a little less congestion. Those would affect utility, but perhaps no more than the inevitable variation in the weather. But in renewable resource extraction problems, variation leads to either collapse or abundance, provided that behavior does not change. Figure 23.1 assumes an average regeneration rate of 25% and 100 units of a resource. Given those assumptions, the equilibrium consumption level equals 20 units per year. The figure assumes a variable growth rate randomly drawn between 20% and 30%. The model also builds in a maximal level of the resource set to 150.

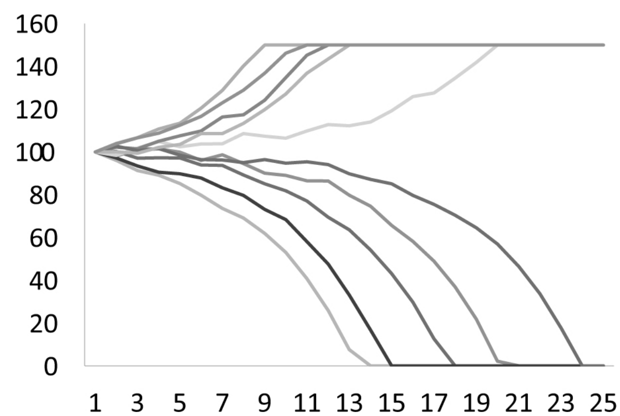

Figure 23.1: Ten Possible Paths Assuming Variation in Growth Rate of Resource

In approximately half of the paths, the level of the resource collapses. In the other half, the level of the resource increases to the maximum possible level. The variation does not cancel out. To the contrary, the effect of a reduction or increase in growth accumulates over time.[13] From this simulation, we see that optimal consumption policy would call for less consumption following lean years to prevent collapse.

Given that variation in the growth rates of a renewable resource requires consumption to vary with the resource level, we know that communities that manage a renewable resource must be able to adjust extraction levels.

The method or mechanism used to make those adjustments depends on features of the resource. To borrow a phrase, "There are no panaceas."[14] No single solution will work in all cases. How local populations solve these types of problems depends on characteristics of the resource and the community.

Fish differ from cattle. A community managing multiple herds of cattle sharing a commons can monitor the behavior of individuals and the level of the resource (the amount of grass). Overgrazing can be solved by rotation schemes that allocate to each individual set times or zones for grazing. These rotations can adjust grazing based on the height of the grass. But for communities that fish, managing the resource requires more elaborate institutions that can precisely monitor individual behavior. The number of fish in the sea cannot be counted. It can only be estimated based on catches. The resource extraction problem has much more uncertainty than the cattle situation. Managing a common aquatic resource requires conservatism and more monitoring.

Collective Action Problems: Solved and Unsolved

In collective action problems, the outcomes that result from self-interested behavior do not align with the goals of the individuals. As noted, these problems occur in myriad settings. They arise in paying for non-rival and non-excludable goods. They arise in decisions for when to drive on highways. They even arise in how we drive on highways. Drivers on a busy highway who tailgate or talk on their cellphones may not take into account the costs of those actions to all of the cars behind them if an accident occurs.

Such problems exist at multiple scales. They arise within family interactions: keeping the house clean, making dinner, going shopping, and saving for vacations can all misalign individual incentives and collective well-being. They exist with communities, regions, and countries in the provision of public goods and the use and management of limited resources. They also exist at a global scale in the form of carbon emissions. Most countries would prefer to produce more energy themselves (which emits more carbon) but have lower global emission levels: individually rational actions do not align with the common good.

Collective action problems occur in the natural world as well. Trees in a forest compete for light and water. If a tree species evolves a higher canopy or deeper roots, it will increase its own chances of survival but impose a cost on other species of trees. The trees cannot pass laws to prevent growing too tall or tapping into deeper water. They do not achieve the socially optimal solution.[15]

Collective action problems tend to be easier to solve the smaller and more homogeneous the group of individuals or actors involved and the better the information (i.e., actions are easier and the state of the system can be monitored). While families generally solve collective action problems, international organizations find cooperation much harder. Efforts to reduce carbon emissions require coordination among a large group of diverse actors using imprecise monitoring mechanisms. Solving such a problem requires coordination as well as an enforcement mechanism. History teaches us that overfishing waters or overgrazing meadows invites the risk of collapse. We can apply that same reasoning to the collective action problems we face today. Elinor Ostrom, who spent decades studying real-world efforts to solve collective action problems, found that in addition to monitoring deviations, communities that solve collective action problems agree on clear boundaries, agree on well defined rules, grant the authority to impose graduated sanctions, and establish mechanisms to resolve disputes.[16]