CHAPTER 10

International environmental problems

The nation-state is here to stay for the near horizon. Thus, practical solutions for today's global challenges must adjust for this reality.

Learning objectives

During the course of this chapter we address a set of important questions that relate to international environmental problems. After studying this chapter, the reader should understand the implications of these questions, be able to answer them in general terms, and have the ability to apply those general answers to specific international environmental problems.

The questions we deal with are as follows:

- In which ways do international environmental problems differ from purely national (or sub-national) problems?
- What additional issues are brought into contention by virtue of an environmental problem being 'international'?
- What insights does the body of knowledge known as game theory bring to our understanding of international environmental policy?
- What determines the degree to which cooperation takes place between countries and policy is coordinated? Put another way, which conditions favour (or discourage) the likelihood and extent of cooperation between countries?
- Why is cooperation typically a gradual, dynamic process, with agreements often being embodied in treaties or conventions that are general frameworks of agreed principles, but in which subsequent negotiation processes determine the extent to which cooperation is taken?
- Is it possible to use such conditions to explain how far efficient cooperation has gone concerning acid rain, lower-atmosphere ozone, and greenhouse-gas pollution?

Introduction

Previous chapters have shown that markets are likely to generate inefficient outcomes in the presence of externalities and public goods. The interdependencies that they create are not, and cannot be, adequately addressed through unregulated market mechanisms. However, when all generators and victims of an externality – or all individuals affected by a public good – reside within a single country, mechanisms exist by which government may be able to induce or enforce an efficient resource allocation where markets fail to do so.1 These mechanisms can operate because the primacy given to the nation state in political affairs provides the legitimacy and authority needed to support them.

However, many important environmental problems concern public goods or external effects where affected individuals live (or are yet to live) in many or all nation states. These international and global environmental problems are the subject of this chapter. Important examples include global warming, ozone-layer depletion, acid rain, biodiversity loss, and the control of infectious diseases. One property common to these problems is that the level of an

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1 There are two important caveats here. First, where there is widespread dispute about the appropriate boundaries of a nation state, government may not possess the legitimacy required to secure compliance with its regulations. Second, even where it is legitimate, government may have insufficient information or means to achieve efficient outcomes.
environmental cost borne, or benefit received, by citizens of one country does not depend only on that country’s actions but also depends on the actions of other countries. Reflect for a moment on these examples. It is evident that in each case the relevant costs and benefits depend on the behaviour of many nations. This adds an important dimension to environmental analysis. Where environmental impacts spill over national boundaries, there is typically no international organisation with the power to induce or enforce a collectively efficient outcome. Will countries behave selfishly in these circumstances? If so, what will be the consequences of that behaviour? Does mutually beneficial cooperation take place between independent nation states? If it does, how large are the gains from that cooperation? And what can be done to increase the chances of cooperative behaviour? These are the kinds of questions we try to answer in this chapter.

We begin our consideration of international environmental problems by discussing international environmental agreements. Box 10.1 lists some characteristics of such agreements. The items in this list are ‘stylised facts’ – assertions that are widely accepted as being valid statements about the phenomena being studied. Subsequent sections of this chapter will illustrate these stylised facts with several examples, and will use economic theory to explain and support them.

The main tool used to explain these assertions is game (or games) theory. Game theory analysis of international environmental problems has been one of the major developments in the recent environmental economics literature. We begin by looking at a simple two-country, two-strategy game played just once. This simple model is then generalised to take account of many countries, continuous rather than discrete choices (for example, how much pollution abatement rather than whether or not to abate pollution), and games played repeatedly rather than just a single time.

Game theory is applied here in the context of decisions about the provision of an international public good. This focus is taken because many – if not most – international and global problems concern the provision (or maintenance) of public goods, and because the theory of public goods has underpinned much of the recent literature about international and global environmental problems. However, much of the content of this chapter could also be interpreted in terms of externalities that spill over national boundaries.

In addition to the examples discussed as we go along, the chapter also examines in greater depth the problems of global climate change, acid rain and depletion of the ozone layer. As you read through these cases, you will see the power of insight that game theory brings to bear on these problems. The chapter concludes by looking at the trade–environment relationship. The notion that free trade can improve economic welfare is a central tenet of economic theory. It goes some way to explain the attachment that many economists have to measures that liberalise international trade. However, free trade may not be welfare-enhancing once environmental impacts are brought into the picture. We explore the conditions under which trade liberalisation is likely to have beneficial – and deleterious – environmental consequences.

Questions at the end of the chapter – and the Additional Materials for Chapter 10 – invite you to apply the ideas developed in this chapter to other important examples: tropical deforestation, wilderness conversion and the loss of biological diversity.

10.1 International environmental cooperation

More than 170 international environmental treaties have been adopted to date, covering a wide range of actual or potential environmental problems. Many of the early treaties concerned regulation of behaviour at sea: marine fishing (see Chapter 17), transportation in international waters, dumping and disposal of wastes, and exploitation of the sea beds. Another set related to regional pollution spillover problems. In recent years, great attention has been paid to attempts to develop agreements about the use

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2 Further details of these international treaties can be found in Treaties.doc in Additional Materials, Chapter 10. A hyperlink from there points you to various summary listings of these treaties available on various web sites, and to a variety of sources of further information about international environmental agreements.
of two global public goods: composition of the atmosphere and the stock of biological diversity.

The main vehicle that has been used in attempts to reach cooperative solutions to regional and global environmental problems is that of the intergovernmental conference. The proactive role played by the United Nations (UN) system of international institutions has been one of the successes of international diplomacy in the post-Cold War period. The adoption of a treaty through such a framework does not of itself imply that objectives and targets will be met. However, the moral, financial and political pressures that such treaties can bring to bear may be large. Also noteworthy is the way in which the UN environmental strategy has attempted to link issues of environmental protection, environmental sustainability and economic development (the latter particularly in the poorer nations).

Initiatives through the United Nations are not the only, or even the most important, framework within which international environmental cooperation has taken place. Much of what is important has been dealt with at regional or bilateral levels, and takes place in relatively loose, informal ways. Why is there a need for international treaties at all? The answer to this question has already been sketched out in the Introduction. Political sovereignty resides principally in nation states. And as the epigraph to this chapter suggests, that state of affairs is likely to remain so for the foreseeable future. There is one important exception to this statement. Countries of the European Union have moved some way towards creating a supranational political institution. However, it is not yet evident that member states have relinquished substantial sovereign power to the European Union.

The environmental impacts of economic activity do not respect national boundaries, however. As the scale and pervasiveness of these activities increases, so the proportion of activity that has international (rather than intra-national) consequences rises, or at least becomes more evident to us. In the absence of a formal supranational political apparatus with decision-making sovereignty, the coordination of behaviour across countries seeking environmental improvements must take place through other forms of international cooperation. Formal international treaties represent the most visible outcome of that cooperation.

How effective has international cooperation been? Does it merely reflect what countries would have done anyway, and so offers little real improvement over the status quo? Or have there been significant environmental (and efficiency) gains arising from cooperation? Three often-repeated assertions about effectiveness warrant particular attention:

- Treaties tend to codify actions that nations were already taking.
- When the number of affected countries is very large, treaties can achieve very little, no matter how many signatories there are.
- Cooperation can be hardest to obtain when it is needed most.

We shall examine the validity of these, and a series of related, assertions in this chapter. To set the scene – and to provide an agenda of issues for analysis in later sections – we present, in Box 10.1, a set of 'stylised facts' about international environmental cooperation. There is now a huge literature on the economics and politics of international environmental agreements. The stylised facts listed in the box have been extracted from conclusions that have been found with some regularity in that literature. Nevertheless, you should treat these as hypotheses rather than facts, and examine them in the light of the evidence given – and the theoretical explanations offered – in the chapter.

10.2 Game theory analysis

A powerful technique for analysing behaviour where actions of individuals or firms are interdependent is game theory. We shall make extensive use of game theory to investigate behaviour in the presence of global or regional public goods. The arguments

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4 This section, and others in the chapter, draw heavily on the works of two writers: Todd Sandler and Scott Barrett. Sandler's book Global Challenges (1997) is a superb non-technical account of game theory applied to international environmental problems. The sequencing and much of the content of our game theory arguments owe much to the pieces by Barrett listed in the Further Reading to this chapter.

4 The games we shall consider here are played by two or more countries. Another variant of game theory is known as games against nature, which is concerned with choices by just one player under conditions of uncertainty.
In all Prisoner’s Dilemma games, there is a single Nash equilibrium (the outcome highlighted in bold in Figures 10.2 and 10.3). This Nash equilibrium is also the dominant strategy for each player. Moreover, the pay-offs to both countries in the dominant strategy Nash equilibrium are less good than those which would result from choosing their alternative (dominated) strategy. As we shall see in a moment, not all games have this structure of pay-offs. However, so many environmental problems appear to be examples of Prisoner’s Dilemma games that environmental problems are routinely described as Prisoner’s Dilemmas.

10.2.1.1.2 Cooperative solution

Suppose that countries were to cooperate, perhaps by negotiating an agreement. Would this alter the outcome of the game? Intuition would probably lead us to answer yes. If both countries agreed to abate – and did what they agreed to do – pay-offs to each would be 3 rather than 0. So in a Prisoner’s Dilemma cooperation offers the prospect of greater rewards for both countries, and superior environmental quality.

But there is a problem here. Can these greater rewards be sustained? If self-interest governs behaviour, they probably cannot. To see why, note that the \{Abate, Abate\} outcome is not a Nash equilibrium. Each country has an incentive to defect from the agreement – to unilaterally alter its strategy once the agreement has been reached. Imagine that the two countries are at the cooperative solution, and then look at the incentives facing Y. Given that X has chosen to abate, Y can obtain an advantage by defecting from the agreement (‘free-riding’), leaving X to abate but not abating itself. In this way, country Y could obtain a net benefit of 5 units. Exactly the same argument applies to X, of course. There is a strong incentive operating on each player to attempt to obtain the benefits of free-riding on the other’s pollution abatement. These incentives to defect from the agreement mean that the cooperative solution is, at best, an unstable solution.

10.2.1.1.2.1 A binding agreement? Is it possible to transform this game in some way so that the \{Abate, Abate\} strategy pair becomes a stable cooperative solution? There are ways in which this might be done, several of which we shall examine later in the chapter. One possibility would be to negotiate an agreement with built-in penalty clauses for defection. For example, the agreement might specify that if either party defects (pollutes) it must pay a fine of 3½ to the other. If you construct the pay-off matrix that would correspond to this agreement, it will be seen that the game structure has been transformed so that it is no longer a Prisoner’s Dilemma game. Moreover, both countries would choose to abate.

But we should be hesitant about accepting this conclusion. Countries might make such promises but, given the incentive to defect, would they keep them or could they be made to keep them? As we have seen there is an incentive to renege on promises here. Cheating (or reneging or free-riding) on agreements might confer large gains on individual cheaters, particularly if the cheating is not detectable. And countries could only be forced to keep their promises (or pay their fines) if there were a third party who could enforce the agreement. So to secure the collectively best outcome, and to make the agreement binding in a game-theory rather than legal sense, it would seem that an enforcer is required. But in a world of sovereign states, no such enforcer exists. So agreements between nations must be self-enforcing if they are to be sustained. The only self-enforcing equilibrium here seems to be the non-cooperation outcome.

All of this suggests that cooperation cannot be relied upon to prevail over individual countries acting non-cooperatively in ways which they perceive to be in their own interests. Non-cooperative outcomes

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Later in this chapter we shall give a precise explanation of what is meant by a self-enforcing agreement.
can and do happen, even where it would be in the interest of all to behave cooperatively. It is for this reason that the game we have been discussing was called a dilemma. Players acting in an individually rational way end up in a bad state. If they attempt to collaborate, incentives on the other to cheat on the deal expose each to the risk of finishing up in the worst of all possible states. Mutual defection seems to be inevitable.

Fortunately, not all games have the structure of the Prisoner’s Dilemma. And, despite what has been said above, we shall see there may be ways in which a Prisoner’s Dilemma game could be successfully transformed to a type that is conducive to cooperation. Box 10.2 briefly describes two other forms of game – the Assurance Game and the Chicken Game – that are useful in exploring international environmental problems.

**Box 10.2 Other forms of game**

Not all games have the form of the Prisoner’s Dilemma. Indeed, Sandler (1997) states that there are 78 possible ordinal forms of the 2-player, 2-strategy game, found from all the permutations of the rankings 1 through to 4. Two other structures of pay-off matrix appear to be highly relevant to environmental problems. These structures generate the Chicken game and the Assurance game.

**Chicken game**

Let us revisit the previous game in which each of two countries must choose whether or not to abate pollution. We suppose, as before, that each unit of pollution abatement comes at a cost of 7 to the abater and, being a public good, confers benefits of 5 to both countries. However, in this example, doing nothing exposes both countries to serious pollution damage, at a cost of 4 to both countries. The pay-off matrix for this ‘Chicken game’ is presented in Figure 10.4. The only difference between this set of payoffs and that in Figure 10.2 is the negative (as opposed to zero) pay-offs in the cell corresponding to both countries selecting *Pollute*.

This difference fundamentally changes the nature of the game. Consider, first, non-cooperative behaviour. Neither player has a dominant strategy. Moreover, there are two Nash equilibria (the cells in bold).

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6 The description ‘Chicken game’ comes from the fact that this form of pay-off matrix is often used to describe a game of daring in which two motorists drive at speed towards each other. The one who loses nerve and swerves is called Chicken. Relabelling the strategy *Pollute* as *Maintain Course* and *Abate* as *Swerve* generates a plausible pay-off matrix for that game.

7 If you transform the Chicken game pay-off matrix into its ordinal form, you will see that the difference in ordinal forms of the Prisoner’s Dilemma and the Chicken game lies in the reversal of the positions in the matrices of the 1 and 2 rankings.

8 A commitment or a reputation might be interpreted in this way. That is, the other player (in this case Y) regards X as already having made their choice of strategy.
Box 10.2 continued

<table>
<thead>
<tr>
<th>X's choice</th>
<th>Y's choice</th>
<th>Pay-off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollute</td>
<td>-4, -4</td>
<td></td>
</tr>
<tr>
<td>Abate</td>
<td>(5, -2)</td>
<td></td>
</tr>
<tr>
<td>Pollute</td>
<td>(-2, 5)</td>
<td></td>
</tr>
<tr>
<td>Abate</td>
<td>(3, 3)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 10.5 Extensive form of the Chicken game

relevant for analysis of extensive form. This is illustrated as Figure 10.5. The solution to this game can be found by the method of backward induction. If X chooses Pollute, Y's best response is Abate. The pay-off to X is then 5. If X chooses Abate, Y's best response is Pollute. The pay-off to X is then -2. Given knowledge about Y's best response, X will choose Pollute as her pay-off is 5 (rather than -2 if she had selected Abate).

This is one example of a more general result: in games where moves are made sequentially, it is sometimes advantageous to play first – there is a 'first-mover advantage'. First-mover advantages exist in Chicken games, for example.

Now consider another possibility. Suppose there is asymmetry in the top left cell so that the penalty to X of not abating is -1 rather than -4, but all else remains unchanged. (This is no longer a Chicken game, however, as can be seen by inspecting the ordinal structure of pay-offs.) The outcome of this game is determinate, and the strategy combination corresponding to the top right cell will be chosen. Backward induction shows that X has a dominant strategy of Pollute. Given that Y expects X to play her dominant strategy, Y plays Abate.

This is reminiscent of decisions relating to ozone-layer depletion. For a while, at least, some countries expected the USA to reduce ozone-depleting emissions, and were content to free-ride on this. Indeed, the USA did play a major role in leading the way towards reducing their use of ozone-depleting substances. Two reasons seemed to lie behind this. First, US EPA studies published in 1987 had shown that health costs from ozone depletion were dramatically higher than control costs. (Specifically, a 50% cut in CFC emissions was estimated to create long-term benefits in the form of avoided cancer damage valued at $6.4 trillion; while long-run abatement costs would be in the range $20–40 billion.) Second, chemical businesses in the USA were confident of being able to achieve competitive advantage in the production of substitute products to CFC substances. The USA would be in a very strong position were a CFC ban to be introduced. Overall, the USA perceived that the benefits to her of abatement were high relative to the benefits of not abating. This was not true for all countries, however, and it is this that creates an asymmetry in the pay-off matrix. Those countries which were, initially at least, free-riders had less relative advantage in abating.

Cooperative behaviour

A strategy in which both countries abate pollution could be described as a cooperative solution to the Chicken game as specified in Figure 10.4. The mutually abate strategy is collectively best for the two countries. But that solution is not stable, because it is not a Nash equilibrium. Given the position in which both countries abate, each has an incentive to defect (provided the other does not). A self-enforcing agreement in which the structure of incentives leads countries to negotiate an agreement in which they will all abate and in which all will wish to stay in that position once it is reached does not exist here. However, where the structure of pay-offs has the form of a Chicken game, we expect that some protective action will take place. Who will do it, and who will free-ride, depends on particular circumstances.

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9 However, some other structures of pay-off matrix lead to the opposite result, in which it is better to let the other player move first and then take advantage of that other player.

10 Dixit and Nalebuff (1991) give a more complete account of the reasoning that lies behind strategic choices in these kinds of games.

11 Some later (1989) US EPA estimates are presented in Table 10.5 below. While the estimates are rather different, the huge surplus of benefits over costs remains in the later figures.
Box 10.2 continued

Assurance game

The other game-form to which some attention will be given in this chapter is the Assurance game. We consider this in terms of an example in which each of two countries must decide whether or not to contribute to a global public good. The cost to each country of contributing is $8. Benefits of $12 accrue to each country only if both countries contribute to the public good. If one or neither country contributes there is no benefit to either country. What we have here is a form of threshold effect: only when the total provision of the public good reaches a certain level (here 2 units) does any benefit flow from the public good. Situations in which such thresholds exist may include the control of infectious disease, conservation of biodiversity, and the re-introduction of species variety into common-property resource systems. The pay-off matrix which derives from the cost and benefit values described above is given in Figure 10.6.

Inspection of the pay-off matrix reveals the following. Looking first at non-cooperative behaviour, neither country has a dominant strategy. There are two Nash equilibria (shown in bold in the matrix). Which is the more likely to occur? Perhaps surprisingly, game theory cannot be of much help in answering that question for a single-shot game. However (as we show later), if the game were to be played repeatedly there is a strong presumption that both would contribute. Moreover, the greater is the difference between the payoffs in the two Nash equilibria, the more likely is it that the 'both countries contribute' outcome will result.

The cooperative solution is that in which both contribute. This solution is stable because it is self-enforcing. If one player cooperates, it is in the interest of the other to do so too. Once here, neither would wish to renegoate. The incentive structure here is supportive of cooperation.

10.2.2 Games with multiple players

The analysis so far has been restrictive, as it has involved only two-country games. But most international environmental problems involve several countries, and global problems a large number. However, much of what we have found so far generalises readily to problems involving more than two countries. Let $N$ be the number of countries affected by some environmental problem, where $N \geq 2$.

We begin by revisiting the Prisoner’s Dilemma example, discussed first in Section 10.2.1.1. As before, each unit of pollution abatement comes at a cost of 7 to the abating country, it confers benefits of 5 to the abating country and to all other countries. For the case where $N = 10$, the pay-off matrix can be described in the form of Table 10.1.

<table>
<thead>
<tr>
<th>A’s strategy</th>
<th>B’s strategy</th>
<th>Do not contribute</th>
<th>Contribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do not contribute</td>
<td>0, 0</td>
<td>0, -8</td>
<td></td>
</tr>
<tr>
<td>Contribute</td>
<td>-8, 0</td>
<td>4, 4</td>
<td></td>
</tr>
</tbody>
</table>

Figure 10.6 A two-player Assurance game

Table 10.1 The Prisoner’s Dilemma example with 10 countries

<table>
<thead>
<tr>
<th>Number of abating nations other than $i$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nation $i$ pollutes</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>Nation $i$ abates</td>
<td>-2</td>
<td>3</td>
<td>8</td>
<td>13</td>
<td>18</td>
<td>23</td>
<td>28</td>
<td>33</td>
<td>38</td>
<td>43</td>
</tr>
</tbody>
</table>
Abate, any individual country does better by reneging on the agreement and polluting.

As before, the structure of pay-offs is critical in determining whether cooperation can be sustained. To explore this idea further, let us think about the pay-offs to choices in a more general way than we have so far. Following Barrett (1997), we denote \( \text{NB}_i \) as the net benefit to a country if it abates and \( \text{NB}_p \) as the net benefit to a country if it pollutes (does not abate). Let there be \( N \) identical countries, of which \( K \) choose to abate. We define the following pay-off generating functions:

\[
\text{NB}_p = a + bK; \quad \text{NB}_i = c + dK
\]

where \( a, b, c \) and \( d \) are parameters. By altering these parameter values, we generate different pay-off matrices. For example, for the problem in Figure 10.2 and in Table 10.1 we have \( a = 0, b = 5, c = -7 \) and \( d = 5 \). You should verify that these two expressions do indeed generate the numbers shown in the examples. Note that for ‘Nation \( i \) pollutes’ row in Table 10.2 \( K \) is equal to the ‘Number of abating nations other than \( i \)’, whereas for the ‘Nation \( i \) abates’ row \( K \) is equal to the ‘Number of abating nations other than \( i \)’ plus 1.

It will be convenient to portray the information shown in Table 10.1 in another way – in the form of Figure 10.7. You should now examine Figure 10.7, and verify that this also represents the information correctly. (If you wish to see the calculations that lie behind this chart, look at the Excel file games.xls.) It is again clear from this chart that the net benefit of pollution is always larger than the net benefit of abating, irrespective of how many other countries abate. The only stable outcome is that in which no countries abate.

But this conclusion is not true for all pay-off structures. For example, suppose that the parameters of the pay-off functions take the following values: \( a = 12, b = 3, c = -7 \) and \( d = 7 \). Then if we generate the counterparts to Table 10.1 and Figure 10.7, we obtain Table 10.2 and Figure 10.8.

It is evident from either of these two descriptions that if less than three countries agree to cooperate (abate), none will cooperate (i.e. all will pollute). However, if three or more cooperate, all will cooperate. Here we have an outcome in which two stable equilibria are possible: either all will abate, or none will. To see that they are both stable equilibria, reason as follows. First, suppose that no country abates. Then, can any country individually improve its pay-off by abating rather than polluting? The answer is no. Next, suppose that every country abates. Can any country individually improve its pay-off by

![Figure 10.7](image_url)

**Figure 10.7** The pay-offs to one country from abating and from not abating as the number of other countries abating varies

<p>| Table 10.2 The Prisoner’s Dilemma example with alternative parameter values |</p>
<table>
<thead>
<tr>
<th>Number of abating nations other than ( i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>Nation ( i ) pollutes</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>Nation ( i ) abates</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
polluting rather than abating? The answer is again no. However, no other combination of polluting and abating countries is stable. For example, suppose that you are polluting and two other countries are abating (and so the remaining seven also pollute). You get 18 and they get 14 each. But each of the two abaters has an incentive to defect (i.e. pollute). For if one were to do so, its pay-off would rise from 14 to 15. Verify that this is so.

As a third example, now consider the parameter set $a = 0$, $b = 5$, $c = 3$ and $d = 3$. This is represented in Table 10.3 and Figure 10.9. This structure of pay-offs generates an incomplete self-enforcing agreement with 3 signatories and 7 non-signatories. Notice that the pay-off to each cooperating (abating) country is lower than that to each non-cooperating country. In this respect the game is similar to a Chicken game. The collective pay-off to all countries is greater than where no cooperation takes place, but is less than from complete cooperation. In this respect, the game is reminiscent of a Prisoner’s Dilemma that has been partly solved. The lesson of this story is that if a Prisoner’s Dilemma pay-off matrix can be transformed by altering the structure of pay-offs (so that, for example, it resembles one of the two later examples) stable cooperation becomes possible. But cooperation may still be less than complete. We will return to this theme in a short while. Before we do so, one further generalisation is necessary.

10.2.3 Continuous choices about the extent of abatement

Our discussion so far has been rather limiting as we have assumed that nations face a simple binary choice decision: participate in an environmental agreement and abate pollution, or do not participate in the agreement and do not abate. But in practice, the relevant decision is not an all-or-nothing choice. Even if one chooses to participate in an agreement, there is a further choice to make: by how much should that country agree to abate the pollutant. Let us now generalise the discussion by allowing countries to choose - or rather negotiate - abatement levels.

This can be done with some simple algebra. Our previous analysis has shown that in terms of the participation choice, three kinds of outcome are possible: none abate, all abate, and some abate but others
do not. For simplicity, we deal first with just the first two of these alternatives. Let us assume that there are \( N \) identical countries, indexed by \( i = 1, \ldots, N \).

We first look at each country's pay-off function. The pay-off functions

Each country is taken to maximise some net benefit (or pay-off) function, \( \Pi_i \). Let \( z_i \) denote pollution abatement by country \( i \), and \( Z = \sum_{i=1}^{N} z_i \) be the total abatement of the pollution. Once again, pollution abatement is taken to be a public good. Then the pay-off (or net benefit) of abatement to country \( i \) is the benefits \( B \) of abatement (which depends on the total amount of abatement by all countries) minus costs \( C \) to country \( i \) of abatement (which depends on its own level of abatement). Thus we have

\[
\Pi_i = B(Z) - C(z_i), \text{ for } i = 1, \ldots, N \tag{10.1}
\]

10.2.3.1 Non-cooperative behaviour

Non-cooperative (or unilateral) behaviour involves each country choosing its level of abatement to maximise its pay-off, independently of and with respect to the consequences for other countries. That is, each country chooses \( z \) to maximise equation 10.1 conditional on \( z \) being fixed in all other countries.

Country \( i \)'s abatement choice is the solution to the first-order condition

\[
\frac{dB(Z)}{dZ} \frac{dZ}{dz_i} = \frac{dC(z_i)}{dz_i} \tag{10.2}
\]

Noting that \( dZ/dz_i = 1 \), and that, given our assumption of symmetry, all countries' efficient abatement will be identical, the solution can be written as

\[
\frac{dB(Z^U)}{dZ} = \frac{dC(z_i^U)}{dz} \quad \text{where} \quad Z^U = \sum_{i=1}^{N} z_i^U \tag{10.3}
\]

and the superscript \( U \) denotes the unilateral (non-cooperative) solution. Intuitively, each country abates up to the point where its own marginal benefit of abatement is equal to its marginal cost of abatement.

10.2.3.2 Full cooperative behaviour

Full cooperative behaviour consists of the \( N \) countries jointly choosing levels of abatement to maximise their collective pay-off. This is equivalent to what would happen if the \( N \) countries were unified as a single country that behaved rationally.\(^{12}\) The solution requires that abatement in each country be chosen jointly to maximise the collective pay-off

\[
\Pi = NB(Z) - \sum_{i=1}^{N} C(z_i)
\]

\(^{12}\) The joint decision process may also involve negotiations about how the additional benefits from cooperation are to be distributed between the parties but we shall leave this matter for consideration later.
The necessary conditions for a maximum are
\[ N \frac{dB(Z)}{dZ} \mid_{Z_i} = \frac{dC(Z_i)}{dZ_i} \quad \text{for all } i. \]

Once again (for the same reasons as given earlier) these can be written as
\[ N \frac{dB(Z^C)}{dZ} = \frac{dC(Z^C)}{dZ} \quad \text{where } Z^C = \sum_{i=1}^{N} z_i^C \]

where the superscript C denotes the full cooperative solution. This is the usual condition for efficient provision of a public good. That is, in each country, the marginal abatement cost should be equal to the sum of marginal benefits over all recipients of the public good.

The full cooperative solution can be described as collectively rational: it is welfare-maximising for all N countries treated as a single entity. Indeed, if some supranational governmental body existed, acting to maximise total net benefits, and had sufficient authority to impose its decision, then the outcome would be the full cooperative solution described here.

The non-cooperative and cooperative solutions can be visualised graphically, and are represented in Figure 10.10. The diagram is adapted from Barrett (1994a). Z denotes pollution abatement. In the absence of cooperation, equilibrium abatement is ZN. Here, each country equates its own marginal benefit of abatement (MBi) and marginal cost of abatement (MCi). In contrast, the full cooperation abatement level ZC has each country equating the sum of the marginal benefit of abatement across all countries (MB) with its own and marginal cost of abatement. This picture is useful because it shows us what determines the size of two magnitudes of interest:

- the amount by which full cooperation abatement exceeds non-cooperative abatement (i.e. Zc - Zn);
- the magnitude of the efficiency gain from full cooperation (the shaded triangular area in the diagram).

It is evident that these depend on two things:

1. the relative slopes of the MB, and MCi curves;
2. the number of competing countries, N (as this determines the relative slopes of the MB, and MB curves).

Problem 10.2 invites you to examine these matters further, and to draw inferences about the conditions under which international cooperation is likely to deliver large decreases in emissions.

10.2.3.3 Partial cooperation and incomplete environmental agreements

As in our earlier analysis of binary-choice decisions, the outcome of a negotiation about an international environmental problem is not restricted to only one of full cooperation or no cooperation at all. A third possibility is partial cooperation: some countries agree to abate pollution (by negotiated amounts), while others act independently, doing the best they can given what the cooperators have agreed. This could be described as an incomplete environmental agreement. In this section, we briefly explore how such incomplete cooperation may be an equilibrium outcome. To do this, we use a concept that has been touched on before, but without being defined: a self-enforcing international agreement.

An agreement is self-enforcing if its terms create incentives on all parties – cooperators and non-cooperators – to adhere to the agreement once it has come into effect. For this to be the case, the agreement must satisfy the following conditions for each country, i = 1, \ldots, N:

- There is no incentive to renegotiate the agreement.
- Pay-offs must be such that cheating is deterred.
• Penalties to countries other than \( i \) should not be a disincentive to country \( i \).
• Penalties to country \( i \) should not encourage country \( i \) to renegotiate.

Let us think about the kinds of choices that have to be made in arriving at such an agreement. First, each country that participates in negotiation of the treaty must decide whether or not to participate. Secondly, the terms of the agreement must be decided upon. These terms concern how much abatement a signatory will undertake. More precisely, this requires a schedule of abatement levels, one for each possible number of other countries acceding to the agreement. Therefore, implicitly or explicitly, the terms include penalties and rewards that reflect what signatories will do if a country were to accede to, or to leave, the group of cooperating countries. This last point is at the heart of how self-enforcing treaties work. Essentially, what happens is that there will be some mechanism whereby if a country accedes the signatories increase their abatement (thus rewarding accession), or reduce their abatement if a country leaves (thus punishing defection).

We can describe this a little more formally as follows. A self-enforcing international environmental agreement (IEA) is an equilibrium outcome to a negotiated environmental problem that has the following properties:

• There are \( N \) countries in total, of which \( K \) choose to cooperate and so \( N - K \) do not cooperate (defect).
• Each cooperating country selects an abatement level that maximises the aggregate pay-off of all countries that cooperate.
• Each defecting country pursues its individually rational unilateral policy.

Choices by each country must also satisfy the two conditions:

• no signatory can gain by unilaterally withdrawing from the agreement;
• no non-signatory can gain by unilaterally acceding to the agreement;

which can be represented by the inequalities \( \Pi_i(k^*) \geq \Pi_i(k^* - 1) \) and \( \Pi_i(k^*) \geq \Pi_i(k^* + 1) \).

10.2.3.4 Key results

The derivation of a solution to this problem is outlined in Appendix 10.1. Several writers have examined what kind of self-enforcing IEA we would expect to see – if any – under a variety of different circumstances. Here we just note some of the main results of that research.

• Non-signatories and signatories would both do better if all cooperate. (In this respect, self-enforcing IEAs resemble a Prisoner's Dilemma game.)
• Non-signatories do better than signatories. (In this respect, the game is like Chicken.)
• Full cooperation is not usually stable (it is not self-enforcing and so renegotiation-proof).
• An IEA may enjoy a high degree of cooperation but only if the difference between global net benefits under the full cooperative and non-cooperative solutions is small; when this difference is large, a self-enforcing IEA cannot support a large number of countries.
• When \( N \) is very large, treaties can achieve very little, no matter how many signatories there are.

Barrett (1994a, 1995) was the first to state these results, and provides the following reasoning and intuition. The larger are the potential gains to cooperation, the greater are the benefits of free-riding and so the larger are the incentives to defect. But the larger are the incentives to defect, the smaller will be the number of signatories. The reason here is that when \( N \) is large, defection or accession by any country has only a negligible effect on the abatement of the other cooperators. This bodes badly for attempts to control greenhouse gas emissions. There the gains from cooperation are very large, and so defection is very likely. Given this, it will be difficult to secure agreement among a large number of countries.

If the test of effectiveness of agreements is by comparison of the Nash and cooperative outcomes, the literature on self-enforcing IEAs suggests that they are very limited in their effectiveness. It suggests that treaties tend to codify actions that nations were already doing. It suggests that a treaty with large numbers of signatories – such as the Biodiversity Convention which has been ratified by more than 140 countries – is limited in its capacity to
deliver social benefits. Compare this case with the Antarctic Treaty which has been ratified by fewer than 25 countries. (See Barrett, 1994a, b and 1995.)  A qualification is in order, however. These results have been derived only for some functional specifications and some possible sets of assumptions (including identical countries, marginal benefits of abatement are constant, and many others). It is not clear how generally robust they are.

10.3 Factors contributing to enhancing probability of international agreements or achieving a higher degree of cooperation

The notion of self-enforcing agreements has proved itself to be a very useful way of thinking about international environmental cooperation. However, as we have seen, it does tend to generate rather pessimistic conclusions about the effectiveness of agreements. Agreements do not have to be self-enforcing; however, there are other mechanisms by which cooperation could deliver large benefits. We discuss several of these in this section.

10.3.1 Role of commitment

Cooperating countries may voluntarily make commitments to do things irrespective of what others do. By giving up the right to change abatement levels in response to changes in K, any agreement that is obtained will not in general be self-enforcing. However, if the commitments are regarded as credible, then – depending on what kinds of commitments are made – it can be possible to achieve and sustain a full (complete) IEA. The difficulty here, of course, is that as commitments typically lead to self-sacrifice in some circumstances, it may be hard to make them credible.

10.3.2 Transfers and side-payments

Suppose that a self-enforcing IEA is only capable of supporting a small number of signatories, K. Now imagine that the signatories offer side-payments to induce non-signatories to enter. If these side-payments are larger than the inducements in the original IEA, others will join in cooperation. In some circumstances, such side-payments can bring about a complete IEA, and so maximise collective benefits. However, as the resulting agreement will, by construction, not be self-enforcing, we have the same difficulty as mentioned in the previous paragraph. Such IEAs may not be credible. It seems that side-payment systems will require that signatories find a way to make a credible commitment to the system (and in effect suspend the self-enforcing constraints).

10.3.3 Linkage benefits and costs and reciprocity

It may be possible to secure greater cooperation than the analysis to date has indicated if other benefits are brought into consideration jointly. Doing this in effect alters the pay-off matrix to the game. To see what might be involved here, we note that countries typically cooperate (or at least try to do so) over many things: international trade restrictions, anti-terrorism measures, health and safety standards, and so on. There may be economies of scope available by linking these various goals. Moreover, reputations for willingness to act in the common interest in any one of these dimensions may secure benefits in negotiations about another. What policy makers might try and obtain is linkages over two or more policy objectives so that the set of agreements about these objectives creates overall positive net benefits for the entire set of participants, and net gains which are distributed so that every participant perceives a net linkage gain. In these cases, there can be very substantial gains from international cooperation.

Of course, it must also be recognised that there may be 'additional' costs of cooperation too. These include transaction and enforcement costs, and perceived costs of interdependency itself (such as feelings about loss of sovereignty). The larger are these costs, the smaller are the possible net gains from cooperation.

10.3.4 Repeated games

Another mechanism that may enhance the extent of cooperation is repeated interaction between nations.
Thus far in this chapter we have implicitly been assuming that choices are being made just once. But most environmental problems are long-lasting and require that decisions be made repeatedly. To examine how this may alter outcomes, let us look first at Figure 10.11 which represents the pay-offs in a one-shot game. Here we suppose that the pay-offs have the ranking \( T > R > P > S \) and that \( S + T < 2R \). The dominant strategy for each player in this game is \( P \).

Now imagine this game being played twice (in two consecutive periods, let us say). The pay-off matrix for this two-shot Prisoner’s Dilemma game, viewed from the first of the two periods, is shown in Figure 10.12. Once again, the dominant strategy is \( P \). In fact, this result is true for any fixed, known number of repetitions. However, observation of actual cooperation and experimental games both suggest that cooperation occurs more commonly than theory predicts. What seems to lie behind this? First, cooperation seems to be more likely when communication is allowed. Most importantly, the likelihood of cooperation increases greatly if interaction is never-ending, or its end point is unknown.

A large literature exists that analyses games played repeatedly. We cannot survey that literature here. Suffice it to say that among the many strategies that are possible, some variety of tit-for-tat strategy seems to be sensible. Tit-for-tat strategies tend to encourage cooperation. However, some results reminiscent of those we have found earlier also emerge. In particular, as \( N \) becomes large, cooperation tends to be more difficult to sustain. Indeed Barrett (1994a) shows that even in infinitely repeated games his previous conclusions remain true: an IEA will only be able to support a large number of signatories when gains to cooperation are small, and when the gains are large a self-enforcing IEA can sustain only a smaller number of signatories. Once again, some form of commitment seems to be required if large gains are to be obtained.

### 10.4 International treaties: conclusions

Many important examples of environmental problem affect only small numbers of countries. Where this is the case, cooperative bargaining agreements are relatively easy to obtain. These can often be embodied in ad hoc agreements and loose structures. Where the number of countries affected by an environmental problem is large, successful cooperation is harder to achieve. These difficulties are lessened if there are large nation-specific gains, and if influential nations are willing to act in the role of leaders. The configuration of pay-offs can be made more conducive to cooperation by linkages between various policy goals (such as debt-for-nature swaps).

### 10.5 Acid rain pollution

Acid rain originates from the emissions of a variety of pollutants that are subsequently chemically converted into acid form, particularly sulphuric and nitric acids. Its international dimension arises from the property that some proportion of the pollutant emissions in question – the precursors of acid rain – are transported over national boundaries by natural processes. Examples include oxides of nitrogen and sulphur, which can be moved over distances of several hundred miles. Unlike greenhouse gases, these substances are not uniformly mixing, and so impacts are regional or international rather than global. Figure 10.13 shows the incremental sulphur dioxide concentrations attributable to a single oil combined cycle power station located near Stuttgart in Germany. Significant \( \mathrm{SO}_2 \) deposits are felt over distances of up to 1000 miles and over most European states.