# Global Trade in $CO_2$ Permits: A Classroom Experiment

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## Abstract

This classroom experiment demonstrates the effects of three different policy scenarios, each designed to achieve the same aggregate reduction in $CO_2$ emissions. Students, taking the roles of managers of electrical power companies, respond first to an across-the-board limit on each firm's emissions. Next, they participate in a national market for tradable $CO_2$ permits. Finally, their governments allow international trade in the permits. National permit trade improves on across-the-board limits, because it allows low-productivity, low-abatement-cost firms to abate and/or cut their electricity production, thereby freeing up their permits to sell to other firms. Global permit trade produces even higher aggregate profits and output of electricity, because it takes full advantage of the lower abatement costs in the developing country and the higher productivity in the developed country. However, some firms' profits fall when global permit trade equalizes the world price of a permit. Under the parameters of our experiment, enough of these losing firms operate in the developing country that its total industry profits decline slightly. Moreover, the developing country's total electricity output declines significantly under global permit trade. The experiment thus inspires a discussion of the particular issues involved in global versus national permit trade. The experiment works in principles of economics, environmental, international, and macro-development economics courses, with 10-80 students. It consists of a preparatory homework assignment, 50 minutes of class time running the experiment, and 15 minutes of follow-up discussion.

## Introduction

In this classroom experiment, each student represents an electrical power company that emits carbon dioxide ($CO_2$). Half of the firms operate in a developed country, and the other half in a developing country. As the managers of these firms, students receive directives from their governments to reduce their $CO_2$ emissions. In the first scenario, each government requires a 40% reduction in emissions per firm. Students must decide whether their firm should abate its emissions, cut its electricity production, or both, in order to comply with the emissions limit. In the second scenario, the governments issue each firm enough $CO_2$ permits to achieve the same 40% reduction in per-firm emissions. Firms may trade these permits, but only within their own country. In the third scenario, the governments issue the same number of tradable permits, but now allow international permit trading.

Each scenario generates a 40% aggregate reduction in $CO_2$ emissions. However, Scenario I, with its across-the-board limit on emissions, imposes the greatest cost on society in terms of lost electricity production and reduced firm profits. The introduction of tradable permits in Scenario II results in higher aggregate electricity production and firm profits. Here, firms with less productive plants cut back on their electricity output so that they can sell their permits at a profit. Similarly, firms with lower abatement costs profit by abating and selling their permits. Firms with more productive plants buy the permits, which means more total electricity gets produced. Thus, tradable permits allow society to reduce the cost of environmental protection, as economists have long suggested (Crocker, 1966, Dales, 1968).

However, the strictly national permit trade in Scenario II does not capture all of the advantages of tradable permits. In contrast, the global trade of Scenario III allows society to take full advantage of the differences in abatement costs and productivity between the two countries. The firms in the developing country can abate relatively cheaply because they typically have not yet adopted the state-of-the art abatement technology more common in the developed country. Their lower abatement costs, and also their lower productivity, mean that firms in the developing country constitute the main sellers of permits. Conversely, firms in the developed country constitute the main buyers of permits, due to their higher productivity and higher abatement costs. This cross-country difference shows up in Scenario II as a high permit price in the developed country, and a low price in the developing country.

Opening permit trade internationally in Scenario III causes permit prices to equalize across countries, and it increases aggregate electricity production and firm profits. Now that firms in the developing country access a market willing to pay more for their permits, they cut back on their production and abate even more. Similarly, firms in the developed country access a market willing to supply permits at a lower price, so they purchase more permits and produce more electricity. Their increased electricity production more than offsets the reduction by the firms in the developing country.

After analyzing the results of their experiment, students see that globally-tradable permits reduce pollution in the least costly manner for society as a whole. So, the experiment makes the case for a market-based solution, specifically one that involves international cooperation. Students find the international angle of this result intuitively appealing. A greenhouse gas such as $CO_2$, which generates a global warming problem, requires a global solution.

However, students also see that changing the permit market from national to global raises a welfare issue for the developing country. Its electricity output falls, even as the developed country's rises. In the follow-up discussion, students might note that the lower electricity production could harm the citizens of this developing country, especially if it means they pay more for electricity. In the experiment, the price of electricity remains exogenously fixed. In the real world, the price paid in the developing country would likely rise relative to the price in the developed world, due to the nontradable nature of electricity. The lost electricity production which caused these higher domestic prices would presumably not be offset by new firms entering the industry. With a constant pool of permits already allocated to the existing firms, additional firms could not afford to start up.

What's more, not every firm benefits from opening the permit market to global trade. Specifically, firms in the developed country who sold permits in their national market see their profits fall when international permit trade lowers the price. Similarly, firms in the developing country who bought permits in their national market see their profits fall when, from their perspective, international permit trade raises the price. In our case, enough of the firms in the developing country actually suffered from the increase in the permit price that the overall profits in the developing country declined very slightly.

The fact that some firms, and even some countries, could lose out under international versus national permit trade could help explain the reluctance of some countries to enter into international pollution control agreements. See, for example, Buchner and Carraro (2004) for a discussion of the incentives particular countries (the U.S., Russia and China) would have to join an emissions trading regime under an agreement like the Kyoto Protocol.[1] This protocol, written in 1997, brings together the developed countries in a pact to reduce $CO_2$ emissions by an average of five percent of their 1990 level, by the 2008-2012 compliance period. Article 17 of the

[1] Buchner and Carraro point out, as we see in our experiment, that changing the composition and number of traders who participate in an emissions trading regime affects the price of the permits and thus the profits of the buyers and sellers.

protocol contains provisions for countries to adopt, at their discretion, a system of tradable pollution permits. However, because this protocol only provides for participation by developed countries, its system of tradable $CO_2$ permits would not take advantage of the significant differences in productivity and abatement costs between the developed and developing world.

The United States generates the most greenhouse gas emissions of any country[2]. The U.S. initially signed the Kyoto Protocol, but withdrew from the agreement in 2001, citing the costs to the U.S. economy and the need for developing countries to also reduce their $CO_2$ emissions. As of early 2004, only forty-five percent of developed countries, in terms of their total $CO_2$ emission in 1990, were signed onto the protocol. With fifty-five percent participation from developed countries bringing the Kyoto Protocol into force, Russia's ratification of the protocol tips the scale (Stavins, 2004).

The Kyoto Protocol's prominent place in current news makes a classroom experiment on permit trading quite topical.[3] Several such experiments already exist in the literature. See Appendix A for a table summarizing the ten others we found, plus our own. Our experiment differs from the others in several respects. First, ours brings in the timely discussion of $CO_2$ emissions and global warming.[4] Second, it demonstrates not only the advantages of tradable pollution permits, but also the advantages and drawbacks associated with making that trade global. Finally, our experiment sheds light on a developed and developing country's motivations for joining an international agreement on such trade.

## Details on Running the Experiment

The experiment contains two parts. Part I consists of Scenario I, where each firm must cut its $CO_2$ emissions by 40%. Part I can be done either in class or as a homework assignment. If done in class, it takes about 20 minutes to read Part I of the instructions aloud, demonstrate

[2] The U.S produced 24% of total global greenhouse gas emissions in 2001 (Earth Policy Institute, 2002).

[3] For more information about the Kyoto Protocol, see the very readable article by Harvard Professor Robert N. Stavins (2004) based, in part, on the notes he used to brief United Nations Secretary-General Kofi Annan.

[4] Olewiler's (2001) experiment uses greenhouse gas emissions as its pollutant, but not in an international context.

how two example firms optimally respond to the policy, and let students privately make and record their decisions for their own firms. Part II begins with the instructor passing out the instructions for Scenario II, where the governments issue nationally-tradable $CO_2$ permits. It takes about 25 minutes to read these instructions aloud, demonstrate how the example firms determine the prices at which each would buy and sell permits, and let students privately figure out the reservation prices for their own firms.

Next, the instructor simultaneously opens two double-oral auction markets, one for each country. Students will mingle in their respective markets, calling out their offers to buy or sell permits. It takes about nine minutes to conduct and record these trades. In this, their first experience trading permits, students need time to get an idea of prevailing prices, so that they can figure out whether they should buy or sell. In fact, in any double oral auction experiment, the limited information about prevailing prices in the first period of trade means that prices don't typically converge to equilibrium. Thus, the instructor generally runs two or three repetitions under identical conditions, and records all trades on the board so that everyone can see the prices. By the third period of trade, prices usually reach or get close to equilibrium. In our experiment, each repetition corresponds to a year's worth of permit trading. That is, in the first period, firms trade permits that allow them to emit a specified amount of $CO_2$ that year. Once the year ends, their permits expire and their government issues them new permits for the next year. In this second year, the instructor again opens the two national trading markets. Nothing from the previous year carries over, so the conditions in this second year of trade exactly replicate the conditions from the first year. However, students do have the information about prices they gleaned from the first year's trade, so prices tend to get closer to equilibrium. We recommend running two or three years of trade in Scenario II. Each year of trade after the first takes only about five minutes, as students become more familiar with the process. Thus, the trading component of Scenario II takes 14-19 minutes altogether.

The instructor introduces Scenario III by handing out the new year's permits, as usual, but also announcing that this year, the governments will allow firms to trade their permits internationally. The two national trading floors merge into one global floor. Again, nothing from past trades carries over to this current year. Two or three years of trade in Scenario III provides sufficient data for the follow-up analysis. Trading and recording the trades take only about four minutes per year now, so all of Scenario III requires 12 minutes or less to run.

Because running the entire experiment in class requires approximately 70 minutes, many instructors will opt to have students do the 20 minutes of Part I at home. This part involves only individual firm decisions, so it makes a straight forward and fairly simple homework assignment. However, the instructor will need to provide an incentive to complete the assignment, so that students come to class prepared to start Part II. Alternatively, instructors can run Parts I and II in class, but break the experiment into two class meetings. For instructors who want to use the last 20 minutes of a class to start the experiment, and can dedicate 50 minutes of the next class to finishing it, breaking after Part I works well. As an alternative option, breaking after 45 minutes also works. This break would occur in the middle of Scenario II, right after the students have determined their reservation prices. A break here gives the less-confident students a chance to confer with the instructor before the actual trading begins in the next class meeting. Although the time estimates described above already include a few minutes for students to privately ask the instructor for help during the experiment, some students might feel better with extra time to reflect between classes.

## Materials for Running the Experiment

At the beginning of the experiment, the instructor gives each student a copy of Part I of the student version of the instructions and also the sheet describing the two example firms. If running Part I in class, the instructor then begins reading aloud from the instructor version of the instructions, starting with Part I. The instructor version exactly replicates the student version of the instructions, except that it includes additional bracketed explanations which help the instructor guide students through the example calculations. For the reader's reference, the instructions and the example firm sheet appear in Appendices B and C. Instructors can email the authors for electronic copies of these sheets plus all of the other materials for running the experiment.

When prompted by the instructions, the instructor hands out to each firm its private information sheet and a copy of the Scenario I record-keeping sheet.[5] These sheets appear in Appendices D and E, respectively. Classes of 20 students work ideally for instructors who wish

[5] Instructors making Part I homework, would distribute the following assignment materials to students: Part I of the student instructions, the example firm sheet, the Scenario I record-keeping sheet, and one of the 10 private firm information sheets. Students would each turn in their Scenario I record-keeping sheet to fulfill the homework assignment.

to have pairs of students manage each of the 10 firms in the experiment. We find pairing students works well. However, students can also manage alone, or in groups of three. Instructors who prefer pairing students and who have classes of 40 could create 20 firms by duplicating each of the 10 firms, and simply giving the new firms new names. We'd recommend similarly creating 30 firms for classes of 60 students, and 40 for classes of 80 students.

At the beginning of Part II of the experiment, the instructor hands out Part II of the student instructions. When prompted by the instructions, the instructor gives each firm its three permits and a record-keeping sheet for the first year of Scenario II. See Appendix F for the Scenario II record-keeping sheet. As each new year starts, the instructor hands each firm three new permits and a new record-keeping sheet. The Scenario III record-keeping sheet looks identical to that of Scenario II, except for the header that identifies it as Scenario III. We recommend printing each year's permits on a different color paper, to distinguish between the years. Printing that year's record-keeping sheets in that same color helps keep the materials organized.

## Experimental Results and Follow-Up Discussion

We ran this experiment in a combined micro-macro principles of economics course at Whitman College. We used it at the end of the semester, in order to tie the micro and environmental economics of the first half of the course together with the macro and international economics of the second half. The experiment worked well as a capstone for our principles course. However, we would also recommend it as fodder for a more advanced discussion in an environmental, international economics or macro/development course. Because participants need familiarity with reasoning on the margin, and in particular with the meaning of marginal product and marginal cost, we recommend running it with students who have already studied these concepts.

To prepare for the follow-up discussion, the instructor will need to collect the firms' record-keeping sheets and (after class) check the students' calculations for accuracy. Admittedly, checking all of the calculations - permits traded, permit price, profit, abatement, and electrical output - can be tedious. To save time, we recommend using the data from only one year of Scenario II and one year of Scenario III. The last year typically provides the best summary of each scenario's results because students have become more familiar with the experiment and better at maximizing their profit. Checking the accuracy of two years of data from ten firms takes about half an hour.

Table 1 shows the Scenario I results when students correctly determine their profit-maximizing abatement under the across-the-board emissions-reduction policy.

**Table 1: Results from Scenario I.**

| Country | Firm | Electricity produced (megawatts) | Pollution generated (before abatement) | Abatement (tons of $CO_2$) | Profits ($) |
|---|---|---|---|---|---|
| X | A | 90 | 300 | 0 | 15,000 |
| X | B | 90 | 300 | 0 | 15,000 |
| X | C | 180 | 300 | 0 | 15,000 |
| X | D | 115 | 400 | 100 | 23,000 |
| X | E | 150 | 300 | 0 | 25,000 |
| Total in Country X | | **625** | | | **93,000** |
| Y | J | 93 | 300 | 0 | 18,000 |
| Y | K | 75 | 400 | 100 | 12,000 |
| Y | L | 95 | 300 | 0 | 20,000 |
| Y | M | 130 | 400 | 100 | 8,000 |
| Y | N | 85 | 300 | 0 | 15,000 |
| Total in Country Y | | **478** | | | **73,000** |
| Global Total | | **1,103** | | | **166,000** |

The instructor creates two tables summarizing the results from Scenarios II and III. See Tables 2 and 3 for example summaries.[6] We recommend projecting Tables 1, 2 and 3 at the start of the class discussion.

[6] The results described in Tables 1-3 and in the rest of the paper come from a summer session run at Whitman College with 12 students who had varying backgrounds in economics. All had taken principles of economics.

**Table 2: Results from One Year of Scenario II.**

| Country | Firm | Electricity produced (megawatts) | Pollution generated (before abatement) | Abatement (tons of $CO_2$) | Permits owned (at the end) | Profits ($) |
|---|---|---|---|---|---|---|
| X | A | 90 | 300 | 100 | 2 | 22,000 |
| X | B | 90 | 300 | 100 | 2 | 17,000 |
| X | C | 240 | 400 | 0 | 4 | 22,000 |
| X | D | 90 | 300 | 100 | 2 | 22,500 |
| X | E | 250 | 500 | 0 | 5 | 29,500 |
| Total in Country X | | **760** | | | | **113,000** |
| Y | J | 113 | 400 | 0 | 4 | 22,000 |
| Y | K | 45 | 200 | 100 | 1 | 13,000 |
| Y | L | 135 | 400 | 0 | 4 | 22,000 |
| Y | M | 130 | 400 | 0 | 4 | 10,000 |
| Y | N | 85 | 300 | 100 | 2 | 15,700 |
| Total in Country Y | | **508** | | | | **85,000** |
| Global Total | | **1268** | | | | **198,000** |
| | | | | | | |
| Permit Sales in Country X: A to C $13,000; B to E $16,000; D to E $14,500 | | | | | | |
| Permit Sales in Country Y: K to J $6,000; N to L $5,700; K to M $5,000. | | | | | | |

**Table 3: Results from One Year of Scenario III.**

| Country | Firm | Electricity produced (megawatts) | Pollution generated (before abatement) | Abatement (tons of $CO_2$) | Permits owned (at the end) | Profits ($) |
|---|---|---|---|---|---|---|
| X | A | 90 | 300 | 100 | 2 | 18,000 |
| X | B | 110 | 400 | 0 | 4 | 16,000 |
| X | C | 300 | 500 | 0 | 5 | 30,000 |
| X | D | 115 | 400 | 0 | 4 | 26,000 |
| X | E | 250 | 500 | 0 | 5 | 42,000 |
| Total in Country X | | **865** | | | | **132,000** |
| Y | J | 93 | 300 | 0 | 3 | 18,000 |
| Y | K | 60 | 300 | 200 | 1 | 18,000 |
| Y | L | 95 | 300 | 0 | 3 | 20,000 |
| Y | M | 100 | 300 | 200 | 1 | 8,000 |
| Y | N | 85 | 300 | 100 | 2 | 20,000 |
| Total in Country Y | | **433** | | | | **84,000** |
| Global Total | | **1298** | | | | **216,000** |
| | | | | | | |
| Permit Sales: A to B $9,000; K to E $9,000; K to E $9,000; M to C $10,000; M to D $9,000; N to C $10,000 | | | | | | |

The instructor first reminds the class that all three scenarios generated the same 40% reduction in global $CO_2$ emissions. The instructor also points out that due to the transboundary nature of $CO_2$ pollution, the world cares about the global total emitted, regardless of where the emissions come from. That is, $CO_2$ generated anywhere in the world contributes to the global warming problem suffered by everyone.

We suggest starting the discussion with an open-ended question such as "Which scenario is best for these countries?" The welfare for the world as a whole, measured by world-wide electricity production and profits, clearly achieves its highest level under Scenario III, and its lowest level under Scenario I. However, students might point out that some firms (namely A, B, J, L and M) have lower profits under the global permit trade of Scenario III than they had under the national trade of Scenario II. In fact, the lower profits of J, L and M more than offset the higher profits of K and N, so that total profit declines slightly in Country Y. This country's total electricity production also declines from Scenario II to III.

Students need to know about country-specific differences between the firms in order to understand why international trade in pollution permits increases aggregate electricity production and profits, while leaving some firms worse off, and resulting in Country Y producing less electricity. In fact, students need to see that X represents a developed country, and Y a developing country. So, the instructor announces that Firms C and N are fairly typical of the electrical power companies in their respective countries, and that by looking closely at C and N, students can understand more about these countries. Next, the instructor projects the private information sheets for these two firms, as shown in Tables 4 and 5.

**Table 4: Electrical Power Company C from Country X**

| Pollution level before abatement (tons of $CO_2$) | Marginal product of electricity (megawatts) | Marginal cost of producing electricity | Marginal benefit of producing electricity [(MPx$1,000)-MC] |
|---|---|---|---|
| 100 | 60 | $100,000 | -$40,000 |
| 200 | 60 | $30,000 | $30,000 |
| 300 | 60 | $35,000 | $25,000 |
| 400 | 60 | $40,000 | $20,000 |
| 500 | 60 | $45,000 | $15,000 |

Marginal cost of pollution abatement per 100 ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $30,000 |
| Second | $35,000 |
| Third | $40,000 |
| Fourth | $45,000 |

**Table 5: Electrical Power Company N from Country Y**

| Pollution level before abatement (tons of $CO_2$) | Marginal product of electricity (megawatts) | Marginal cost of producing electricity | Marginal benefit of producing electricity [(MPx$1,000)-MC] |
|---|---|---|---|
| 100 | 35 | $45,000 | -$10,000 |
| 200 | 25 | $10,000 | $15,000 |
| 300 | 25 | $15,000 | $10,000 |
| 400 | 25 | $21,000 | $4,000 |
| 500 | 25 | $24,000 | $1,000 |

Marginal cost of pollution abatement per 100 ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $5,000 |
| Second | $5,000 |
| Third | $9,000 |
| Fourth | $11,000 |

To draw attention to the differences between these two firms, and thus the general differences between the electrical companies in the two countries, the instructor asks a series of questions. "Which country's firm produces more electricity for each 100 tons of $CO_2$ emitted?" [*Country X.]* "Which country's firm has lower marginal abatement costs for each 100 tons of $CO_2$ emitted? *[Country Y.]* The instructor again projects Tables 1, 2 and 3 and continues to highlight the differences between the countries, now by asking questions about the experimental results. "Which country's firms produced the most electricity in each scenario?" [*Country X.]* "In Scenario III, when the firms could all trade with each other, which country's firms purchased the most permits?" [*Country X.]* "In Scenario III, which country's firms did the most abating?" [*Country Y]*. The instructor then informs the class that one of the countries is a developing country and the other is a developed country, and asks them which they think is which, and how they can tell. *[Country X represents a developed country characterized by very productive electrical plants. Its firms have relatively costly marginal abatement technology because of their state-of-the-art equipment. To make their plants pollute less requires adopting very advanced and therefore expensive abatement technology. In contrast, Country Y represents a developing country characterized by less productive electrical plants. Firms in Country Y could adopt fairly inexpensive abatement technology because they do not yet have in place the state-of-the-art equipment. So, during international permit trade, firms in Country Y cut back on production or* *abate, thereby freeing up permits to sell to firms in Country X. These firms in X produce more electricity per permit than did the firms in Y. Thus the extra electricity produced in X more than offsets the reduction in Y.]*

The instructor also asks why society finds itself better off with permit trade (even if only the national trade in Scenario II) rather than with the across-the-board emissions limits of Scenario I. [*When permit trade replaces a policy of individual firm emissions limits, firms can take advantage of their differences in productivity and abatement costs. For example, a firm in Scenario I can only reduce production or abate based on its own abatement costs and marginal production possibilities. But, allowing this firm to use pollution permits gives it the option of profitably selling them to other firms that can put them to more efficient use. Therefore, the transactions benefit both firms.]*

The instructor now draws student attention to the profits firms earned in Scenarios II and III, as shown in Tables 2 and 3. The class will note that not every firm increased its profits when global trade opened, and that in fact, the total profits in Country Y fell slightly. The instructor would ask why some firms' profits fell. *[Firms A and B in Country X and Firms J, L and M in Country Y all earned lower profits in Scenario III than in Scenario II. Country X, the developed country, had high permit prices in Scenario II. In equilibrium, its permit prices are in the $15,000 range. Firms A and B, both sellers of permits, benefited from these high prices. Country Y, the developing country, had low permit prices in Scenario II. In equilibrium, its permit prices are in the $5000 range. Firms J, L and M bought permits at these low prices. When the global permit trade moved prices to about midway between these two extremes, the sellers of permits in Country X and the buyers of permits in Country Y both earned less profit on their permit transactions.]*

The class would note that opening global permit trade made Country Y's overall profits fall because the lower profits for J, L and M just slightly outweighed the higher profits earned by K and N, the firms that benefited from selling permits at higher prices. However, students should see that our results depend on the particular parameters of our experiment, i.e. the productivity of our firms, their abatement costs, and the number of firms of each type. Different parameters would generate different permit prices, and therefore different profits. In particular, our parameters don't necessarily correspond to the real world. We cannot use our results to predict how the additional profits from global permit trade would end up being distributed between the developed and developing world.

Lastly, the instructor can tie together the day's discussion by asking some students to suppose that they work for the Environmental Protection Agency and that their boss, who does not understand the logic behind tradable emissions permits, asks for a briefing on the potential benefits and drawbacks for a developed country like the U.S. Other students take the role of economic consultants to a developing country, providing it with a briefing on its potential benefits and drawbacks. These consultants would likely refer to the slightly reduced profits of the developing country under Scenario III versus II, and perhaps even suggest that the international agreement should compensate the developing country out of the higher world-wide profits. Students in more advanced classes might also bring up the issues associated with the reduction in electricity production in the developing country.

## Conclusion

The problem of $CO_2$ emissions, with its global effects on the environment, requires a global solution. Our experiment brings this hot topic in current research to the classroom. Economic theory proposes international trade in $CO_2$ emissions to achieve the lowest global economic burden from a particular level of emissions reduction. The results of this experiment reinforce that theoretical prediction. Moreover, participation in the experiment and the analysis of the results show students why the theory holds. Specifically, they see how and why nationally tradable permits provide greater aggregate profits and electricity production than does an across-the-board limit on emissions. They see that internationally tradable permits take full advantage of the differences in abatement costs and productivity between firms in a developing and developed country. International permit trade therefore provides the greatest world wide profits and electricity production. However, some firms in both the developing and developed country earn less profit under global permit trade than they do under national. Also, under our experimental parameters, the developing country's total electricity output significantly declines when permit trade becomes global. Students thus see that the existence of potential losers could make international cooperation harder to achieve. As Stavins (2004) says, "the more one studies international tradable-permit systems to address global climate change, the more one comes to believe that this is the worst possible approach, except - of course - for all the others." (p. 13)

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Appendix A: Comparison of Eleven Classroom Experiments on Pollution Permits Trading

| Author<br>Year | Course | Running Time | Number of Students | Pollution Type | Firm Type | Pollution Reduction Policy Scenarios | Firms' Compliance Options | Firms initially emit varying levels of pollution? | Marginal Abatement Cost | Initial Permit Allocation | Auction Type |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Anderson and Stafford 2000 | principles, environmental economics | 50 min + discussion | 9-36 or more | generic | generic | tradable pollution permits market | abatement, trade permits, reduce production of good | no | constant | equal, then unequal | double-oral |
| Ando and Ramirez 2003 | Principles | 50 min | <30 | any | generic | tradable pollution permits market | abatement, trade permits | yes | increasing | equal | Walrasian auctioneer |
| Bergstrom and Miller 1997 | Principles | 50 – 80 minutes | 15 – 60 or more | generic | lawn ornament | 1. tax on sellers<br>2. tradable pollution permits market | 1. pay tax, stop producing<br>2. trade permits, stop producing | no | NA | unequal | double-oral |
| Grant 2004 | 3rd year environmental economics | One class | 80 | SO2 | electricity producer | tradable pollution permits market | abatement, trade permits | yes | increasing | equal | double-oral |
| Hazlett 1995 | principles, environmental economics | One class | 10-20 | SO2 | electricity producer | tradable pollution permits market | abatement, trade permits, reduce production of good | no | increasing | equal | ascending single-price |
| Hazlett and Bakkensen 2004 | principles, environmental, international, macro/development | 20 min of homework, 50 min + discussion | 10-80 | CO2 | electricity producer | 1. limit on each firm's emissions<br>2. tradable pollution permits (national, then global) market | 1. abatement, reduce production of good<br>2. abatement, trade permits, reduce production of good | no | increasing | 1. NA<br>2. equal | double-oral |
| Kilkinney 2000 | agricultural econ, environmental economics, public finance, rural development | 50 min | 15-60 | hog odor | hog producer | tradable pollution permits market | trade permits | yes, as received through previous hog auction | NA | students vote on number and allocation | double-oral |
| Nugent 1997 | principles, environmental economics | 50 min + discussion | small as is, but can add more firms | air pollution | coal-fired electricity producer | tradable pollution permits market | abatement, trade permits, reduce production of good | no | constant | equal, then unequal | double-oral |
| Olewiler 2001 | 200-level environmental economics, but many variations for other levels | as long or as short as desired | variable | GHG | various | 1. limit on each firm's emissions<br>2. tradable pollution permits market | 1. abatement<br>2. abatement, trade permits | yes | constant | 1. NA<br>2. equal | double-oral |
| Stephenson and Langdon 1997 | intro to environmental economics | paper does not say | 16-32 | nitrogen | wastewater treatment plant | tradable pollution permits market | abatement, trade permits | yes | increasing | equal | double-oral |
| Walbert and Bierma 1988 | principles, environmental economics, or graduate | one class | paper does not say | SO2 | electricity producer | 1. limit on each firm's emissions<br>2. tradable pollution permits market | 1.abatement<br>2.abatement, trade permits | paper does not say (instructor creates firm handouts) | paper does not say | 1. NA<br>2. none, then equal | ascending single-price and double-oral |

Appendix B: **Instructions for the Pollution Reduction Experiment: Part I**
(Instructor version)

You are about to participate in an experiment comparing policies to reduce carbon dioxide emissions. Each of you represents an electrical power company. Your goal is to maximize your firm's profit. Some of you operate your firm in Country X, and the rest operate in Country Y. Each firm is currently emitting 500 tons of carbon dioxide ($CO_2$) per year. Because $CO_2$ is a greenhouse gas that contributes to global warming, your governments have decided to reduce by 40% the total amount of $CO_2$ generated via electricity production. This experiment will implement a series of three different policies, each designed to achieve the 40% reduction.

Under **Scenario I**, your governments require each firm to reduce its individual $CO_2$ emissions by 40%. There are three methods by which your firm could comply with its emissions limit. First, you could cut your electricity production, thereby reducing your associated emissions of $CO_2$. Second, you could invest in abatement technology to reduce your emissions, while still producing the same amount of electricity. Third, you could combine cutting electricity production and using abatement technology. You should use whichever compliance method leaves you the most profit.

Each firm will get a **private information sheet**. This sheet shows the firm's marginal revenue and marginal cost of producing electricity. It also shows the firm's cost of using abatement technology. Each firm will need this information to make decisions about how to reduce its pollution emissions. On the accompanying page, you can see the information sheets for two example firms. We'll refer to these firms throughout the instructions.

Recall that each firm must reduce its $CO_2$ emissions by 40% of it current 500 tons/year. So, each firm must limit its emissions to 300 tons this year. In order to figure out how to maximize the profit of an electric company facing this emissions limit, you first need to know that electricity sells for $1,000 per megawatt. Then, you need to calculate the firm's **marginal benefit** of producing electricity. To calculate the marginal benefit of electricity production at a particular level of $CO_2$ emissions, take the marginal revenue (i.e., the marginal product of electricity at that emissions level, multiplied by the $1,000 price of electricity) and subtract the marginal cost of electricity production. For instance, consider example Firm 1, when it's producing electricity at the emissions level of 100 tons of $CO_2$. Its marginal revenue is the 45 megawatts it produces multiplied by the $1,000 price of a megawatt, i.e. $45,000. So, its marginal benefit of electricity production is its $45,000 marginal revenue minus its $60,000 marginal cost, which equals –$15,000. What is Firm 1's marginal benefit of electricity production at the 200-ton emissions level? *[Answer: $45,000 – $30,000 = $15,000.]* At the 300-ton level? *[Answer: $35,000 – $25,000 = $10,000. We'll go around the room, with each of you calculating one of the remaining marginal benefits, until we have the marginal benefit columns filled in for both example firms.]*

Remember that firms can reduce the amount of $CO_2$ that they emit, while still producing their electricity, if they use pollution **abatement technology**. For instance, if a firm wants to produce electricity at the 400-ton emissions level, then it could emit the 300 tons of $CO_2$ that it's allowed, and use technology to abate (i.e. eliminate) the next 100 tons of $CO_2$. However, the firm does incur a cost when it uses abatement technology. A firm's marginal cost of abatement is shown at the bottom of its sheet. The first number is the cost of abating the first 100 tons, the second number the cost of abating the second 100 tons, and so forth.

To determine **how much $CO_2$ to abate**, a firm compares its marginal cost of abatement with its marginal benefit of getting to produce more electricity. Specifically, if abating 100 tons costs less than the firm's marginal benefit of producing the extra electricity, then the firm would abate. Let's look at Firm 1 to see how much it will abate when it is limited to emitting 300 tons of $CO_2$. If Firm 1 were to abate 100 tons of $CO_2$, it would move to the production level associated with 400 tons of emissions. Then, Firm 1 would receive $5,000 in marginal benefit from electricity production, but it would have to pay $6,000 for the abatement. Its marginal profit would be $5,000 - $6,000 = -$1,000. Therefore, Firm 1 will continue to produce at the 300 ton level and not abate at all. Note that its electricity production will be 45+45+35=125 megawatts, and its profit will be –$15,000 + $15,000 + $10,000 = $10,000.

How will Firm 2 respond to the 300-ton emissions limit? That is, how much will it abate, how much electricity will it produce, and how much profit will it make? *[If Firm 2 were to abate 100 tons of $CO_2$, it would move to the production level associated with 400 tons of emissions. Then, Firm 2 would receive $10,000 in marginal benefit, and only have to pay $7,000 for the abatement. Its marginal profit would be $3,000, so it would want to undertake this abatement. If it were to also abate another 100 tons, it would move to the production level associated with 500 tons of $CO_2$. Then it would receive $9,000 in marginal benefit, but would have to pay $12,000 for that abatement. Its marginal profit to abate that second 100 tons would be -$3,000, so it would not want to undertake that second 100 tons of abatement. Thus, it would abate 100 tons of $CO_2$, and produce at the 400-ton emissions level. It will therefore produce 35+35+25+20=115 megawatts of electricity, and make a profit of –$15,000 + $15,000 + $11,000 + $10,000 – $7,000 = $14,000.]*

*[I will now pass out your firm's private information sheet. Do not share the information on this sheet with other firms.]* You should now determine your firm's profit-maximizing response to the 300-ton emissions limit. First fill in your marginal benefit column. Then, determine the amount of abatement technology you will use, the amount of electricity you will produce, and your profits. Fill in the Scenario I record sheet with the results of your firm's decisions.

Instructions for the Pollution Reduction Experiment: Part II

The chart below shows how economic theory predicts each firm would respond to the 300-ton emissions limit in Scenario I. Check to see if your firm's decisions match these predictions.

| Country | Firm | Abatement (tons of $CO_2$) | Electricity produced (Megawatts) | Profits |
|---|---|---|---|---|
| X | A | 0 | 90 | Private Information |
| X | B | 0 | 90 | Private Information |
| X | C | 0 | 180 | Private Information |
| X | D | 100 | 115 | Private Information |
| X | E | 0 | 150 | Private Information |
| **Total in Country X** | | | **625** | |

| | | | | |
|---|---|---|---|---|
| Y | J | 0 | 93 | Private Information |
| Y | K | 100 | 75 | Private Information |
| Y | L | 0 | 95 | Private Information |
| Y | M | 100 | 130 | Private Information |
| Y | N | 0 | 85 | Private Information |
| **Total in Country Y** | | | **478** | |
| **Global Total** | | **300** | **1,103** | **$166,000** |

Economists suggest that there are cheaper ways to get the same total amount of pollution reduction that we achieved in Scenario I. Instead of insisting on across-the-board reductions in emissions, economists advise issuing tradable pollution permits. In **Scenario II**, the governments implement a system of tradable pollution permits. Your government now requires you to own one pollution permit for every 100 tons of $CO_2$ you emit this year. Each government will give every firm in its country three permits for this year. Thus, your firm could use its three permits to emit 300 tons of $CO_2$ this year. I will now pass out the three permits your government gives you.

You might find it profitable to **acquire more permits** for your firm. If so, you could get a fourth or fifth permit by buying it from other firms in your country. For example, let's figure out what price Firm 1 would be willing to offer to buy a fourth permit. Owning this fourth permit would allow Firm 1 to emit 400 tons of $CO_2$ this year. Its marginal benefit from producing the associated electricity would be $5,000. So, it would be **willing to pay** up to $5,000 for a permit to allow it to produce at this level. Recall that the firm also has the alternative of abating 100 tons to get to this production level. However, because the abatement would cost $6,000, the firm wouldn't abate to get to the 400-ton level.

What would Firm 1 be willing to pay for a fifth permit, allowing it to emit 500 tons of $CO_2$? *[Its marginal benefit from producing the associated electricity would be $4,000. So, it would be willing to pay up to $4,000 for a permit to allow it to produce at this level. Note that because abating would cost $6,000, the firm wouldn't want to abate to get to the 500-ton level.]*

Now consider what Firm 2 would be willing to pay for a fourth permit. You'll note that Firm 2's marginal benefit of reaching the 400-ton level is $10,000. However, Firm 2 is not actually willing to pay that much to buy a fourth permit, because the firm could instead abate that 100 tons of $CO_2$ at a cost of $7,000. So, Firm 2 is only willing to pay up to $7,000 for a fourth permit. Assuming that Firm 2 does buy a fourth permit for $7,000 or less, what would it be willing to pay for a fifth permit? *[Owning a fifth permit would allow Firm 2 to produce at the 500-ton $CO_2$ level. Its marginal benefit of reaching this level is $9,000. However, because the firm hasn't done any abating yet, it could abate its first 100 tons at a cost of $7,000. So, it's not actually willing to pay $9,000 for a fifth permit. Instead, it's willing to pay up to $7,000.]*

Take a minute now to privately determine what price you would be willing to pay to buy a fourth permit for your own firm. Then determine what price you'd be willing to pay to buy a fifth permit.

You would want to **sell a permit** if you would make more money selling it than you would make from using it. Consider whether to sell your third permit, which allows you to go from emitting 200 to emitting 300 tons of $CO_2$ this year. If the marginal benefit you'd get from being able to sell the associated electricity is less than the price you're being offered for your permit, then you should sell your permit. Note also that paying to abate your emissions can free up your permits to sell to other firms. If one of those firms would pay more for a permit than it costs you to abate, then you'd abate and sell that permit. A good rule of thumb is to sell a permit as long as you receive a price that at least covers your cost of abating, or your marginal benefit from using your permit to produce electricity, whichever is lower.

For instance, consider **Firm 1**. It receives $10,000 of marginal benefit from using its **third permit** to produce at the 300-ton level. Suppose Firm 1 was offered $7,000 to sell that permit. It could profitably accept, because it could substitute abating (at a cost of $6,000) for using the permit. So, the firm would sell this permit for $7,000, abate, and continue producing at the 300-ton level. Selling the permit for $7,000, abating at a cost of $6,000, and getting the $10,000 in marginal benefit of electricity production leaves the firm with a marginal profit of $7,000 - $6,000 + $10,000 = $11,000. That $11,000 is better than the $10,000 in marginal benefit the firm would have had from using its third permit itself. Note that Firm 1 is applying the rule of thumb here. It had $10,000 in marginal benefit of electricity production, and $6,000 in marginal cost of abatement, so it was willing to sell that permit for any price greater than $6,000.

Suppose that Firm 1 has sold its third permit and is now being offered $9,500 to sell it's **second permit.** It could profitably accept, because it could substitute abating (at a cost of $9,000) for using that permit. So, the firm would sell its second permit for a price of at least $9,000, abate, and continue receiving the $10,000 in marginal benefit from producing at the 300-ton level. Note that by selling the permit for $9,500 and abating at a cost of $9,000, it comes out ahead by $500.

At what price would **Firm 2** be willing to sell its **third permit**? Firm 2 is in a slightly different position than Firm 1, because Firm 2 knows that even if it doesn't sell any permits, it will abate. Why? Because abating its first 100 tons costs $7,000, which is worth paying to get the $10,000 in marginal benefits from being able to produce at the 400-ton level. Let's think of Firm 2 as already having decided to abate at least 100 tons. Now suppose it's being offered a price of $10,500 to sell its third permit. If it sold that third permit, it could either substitute abating (at a cost of $12,000) for using the permit, or it could simply do without the permit and drop back to producing at the 300-ton level. Dropping back means that it gives up the $10,000 in marginal benefit that it had from producing at the 400 ton level. Accepting the permit sale price of $10,500 would be worth forgoing the $10,000 in marginal benefit, so the firm would accept and drop back. Note that Firm 2 is applying the rule of thumb here. It had $10,000 in marginal benefit of electricity production, and $12,000 in marginal cost of abatement, so it was willing to sell that permit for any price greater than $10,000.

Suppose that Firm 2 has sold its third permit and is now being offered $13,000 to sell its **second permit**. If it sold that second permit, it could either substitute abating (at a cost of $12,000) for using the permit, or it could simply do without the permit and drop back to producing at the 200-ton level. Dropping back means that it gives up the $11,000 in marginal benefit that it had from producing at the 300 ton level. Selling the permit for $13,000 would be worth forgoing the $11,000 in marginal benefit, so the firm would accept and drop back. Note that Firm 2 is applying the rule of thumb again. It had $11,000 in marginal benefit of electricity production, and $12,000 in marginal cost of abatement, so it was willing to sell that permit for any price greater than $11,000. Note also that dropping back and forgoing the marginal benefit was better for the firm than abating, because giving up $11,000 was better than paying $12,000.

Take a minute now to privately figure out the lowest price your firm would be willing to accept to sell your third permit. Also, if you've sold your third permit, what is the lowest price you'd be willing to accept to sell your second permit?

Firms will buy and sell permits in a **double-oral auction**. Buyers and sellers will mingle, calling offers to buy and offers to sell permits, at prices they specify. Remember that buyers want to pay low prices and sellers want to get high prices. Any buyer may accept any seller's offer, and vice versa. You may buy or sell as many permits as you choose, from as many different firms as you choose, but only from firms in your own country. Country X firms will meet and trade in this part of the room, and Country Y firms in that part. Once you have conducted a trade, come to the front of the room to report the buyer's ID, the seller's ID, and the permit price. I will record this information on the board for everyone to see. You can then go back to your country's trading floor and buy or sell more permits, if you choose. Once you are done with all of the trading that could increase your profits, please fill out your Scenario II record sheet.

> *[Now that you have finished trading permits and have filled out your Scenario II record sheet for Year One, we are going to start Year Two of Scenario II. The permits from Year One have expired. So, at the beginning of Year Two, each government again issues three tradable permits to every firm in its country. Thus, each of your firms starts in the exact same position that it started Year One. In fact, it's as if Scenario II starts anew, with nothing from Year One carrying over into Year Two. In particular, you start again at the top of your abatement cost schedule, regardless of whether you abated any last year. I will pass out your Year Two permits, and then I will open the market for permit trade.]*

*[Scenario III*

*Economists suggest that opening international trade in pollution permits would further lower the cost of pollution reduction. Your governments have agreed to try this suggestion. So, in Scenario III, your governments will again issue you each three permits for this year. They will allow you to trade these permits with firms in your country and in the other country. Thus, each of your firms starts in the exact same position that it started every year of Scenario II, except that now you can trade your permits internationally. I will pass out your permits for this year, and then you can begin trading permits.]*

Appendix C: **Private Information Sheets for Two Example Firms**

## Electrical Power Company 1

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 45 | $60,000 | |
| 200 | 45 | $30,000 | |
| 300 | 35 | $25,000 | |
| 400 | 30 | $25,000 | |
| 500 | 24 | $20,000 | |

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $6,000 |
| Second | $9,000 |
| Third | $12,000 |
| Fourth | $15,000 |

## Electrical Power Company 2

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 35 | $50,000 | |
| 200 | 35 | $20,000 | |
| 300 | 25 | $14,000 | |
| 400 | 20 | $10,000 | |
| 500 | 14 | $5,000 | |

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $7,000 |
| Second | $12,000 |
| Third | $14,000 |
| Fourth | $16,000 |

## Appendix D: **Private Information Sheets for the Ten Firms**

**Country X** **Electrical Power Company A: Private Information Sheet**

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 35 | $55,000 | |
| 200 | 30 | $10,000 | |
| 300 | 25 | $10,000 | |
| 400 | 20 | $15,000 | |
| 500 | 20 | $15,000 | |

Electricity sells for $1,000 per megawatt.

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $6,000 |
| Second | $15,000 |
| Third | $16,000 |
| Fourth | $17,000 |

**Country X** **Electrical Power Company B: Private Information Sheet**

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 40 | $55,000 | |
| 200 | 25 | $10,000 | |
| 300 | 25 | $10,000 | |
| 400 | 20 | $10,000 | |
| 500 | 20 | $15,000 | |

Electricity sells for $1,000 per megawatt.

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $14,000 |
| Second | $18,000 |
| Third | $20,000 |
| Fourth | $25,000 |

**Country X** **Electrical Power Company C: Private Information Sheet**

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 60 | $100,000 | |
| 200 | 60 | $30,000 | |
| 300 | 60 | $35,000 | |
| 400 | 60 | $40,000 | |
| 500 | 60 | $45,000 | |

Electricity sells for $1,000 per megawatt.

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $30,000 |
| Second | $35,000 |
| Third | $40,000 |
| Fourth | $45,000 |

**Country X** **Electrical Power Company D: Private Information Sheet**

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 40 | $50,000 | |
| 200 | 25 | $10,000 | |
| 300 | 25 | $10,000 | |
| 400 | 25 | $10,000 | |
| 500 | 20 | $15,000 | |

Electricity sells for $1,000 per megawatt.

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $12,000 |
| Second | $13,000 |
| Third | $15,000 |
| Fourth | $17,000 |

**Country X** **Electrical Power Company E: Private Information Sheet**

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 50 | $80,000 | |
| 200 | 50 | $20,000 | |
| 300 | 50 | $25,000 | |
| 400 | 50 | $30,000 | |
| 500 | 50 | $35,000 | |

Electricity sells for $1,000 per megawatt.

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

First $22,000
Second $25,000
Third $30,000
Fourth $40,000

**Country Y** **Electrical Power Company J: Private Information Sheet**

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 35 | $55,000 | |
| 200 | 35 | $10,000 | |
| 300 | 23 | $10,000 | |
| 400 | 20 | $10,000 | |
| 500 | 20 | $15,000 | |

Electricity sells for $1,000 per megawatt.

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

First $15,000
Second $16,000
Third $17,000
Fourth $18,000

**Country Y** **Electrical Power Company K: Private Information Sheet**

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 25 | $30,000 | |
| 200 | 20 | $10,000 | |
| 300 | 15 | $10,000 | |
| 400 | 15 | $10,000 | |
| 500 | 15 | $10,000 | |

Electricity sells for $1,000 per megawatt.

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $3,000 |
| Second | $7,000 |
| Third | $11,000 |
| Fourth | $13,000 |

**Country Y** **Electrical Power Company L: Private Information Sheet**

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 35 | $50,000 | |
| 200 | 30 | $10,000 | |
| 300 | 30 | $15,000 | |
| 400 | 30 | $20,000 | |
| 500 | 30 | $25,000 | |

Electricity sells for $1,000 per megawatt.

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $12,000 |
| Second | $13,000 |
| Third | $17,000 |
| Fourth | $19,000 |

**Country Y** **Electrical Power Company M: Private Information Sheet**

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 40 | $65,000 | |
| 200 | 30 | $15,000 | |
| 300 | 30 | $15,000 | |
| 400 | 30 | $20,000 | |
| 500 | 30 | $25,000 | |

Electricity sells for $1,000 per megawatt.

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $7,000 |
| Second | $9,000 |
| Third | $12,000 |
| Fourth | $15,000 |

**Country Y** **Electrical Power Company N: Private Information Sheet**

| Emissions Level Before Abatement (tons of $CO_2$) | Marginal Product of Electricity (Megawatts) | Marginal Cost of Producing Electricity | Marginal Benefit of Producing Electricity [(MPx$1000) – MC] |
|---|---|---|---|
| 100 | 35 | $45,000 | |
| 200 | 25 | $10,000 | |
| 300 | 25 | $15,000 | |
| 400 | 25 | $21,000 | |
| 500 | 25 | $24,000 | |

Electricity sells for $1,000 per megawatt.

Marginal cost of pollution abatement per 100-ton reduction in $CO_2$ emissions:

| | |
|---|---|
| First | $5,000 |
| Second | $5,000 |
| Third | $9,000 |
| Fourth | $11,000 |

## Appendix E: **Scenario I Record-keeping Sheet**

Scenario I

Your Government Limits Your Firm to 300 tons of $CO_2$ Emissions

Record Sheet

Company Name ______________________

Student Names ________________________________________________________

I. Production

Amount of electricity produced in megawatts ______________
Amount of carbon dioxide generated in tons (after abatement) ______________
Amount of abatement undertaken in tons ______________

II. Profits or Losses

Revenue:
Revenue from the sale of electricity ______________

Cost:
Cost of electricity production ______________
Cost of pollution abatement ______________

Total Cost ______________

Profit = Revenue from the sale of electricity - Total Cost ______________

Appendix F: **Scenario II Record-keeping Sheet**

Scenario II: National Trade in Pollution Permits

Record Sheet

Company Name ____________________

Student Names _____________________________________________________

I. Permit Purchases or Sales

Permits purchased: Quantity______ Price (s) _______________________
Permits sold: Quantity______ Price (s) _______________________

II. Production

Amount of electricity produced in megawatts ____________
Amount of carbon dioxide generated in tons (after abatement) ____________
Amount of abatement undertaken in tons ____________

III. Profits or Losses

Revenue:
Revenue from the sale of electricity ____________
Revenue from the sale of permits ____________

Total Revenue ____________

Cost:
Cost of electricity production _____________
Cost of permits purchased _____________
Cost of pollution abatement _____________

Total Cost _____________

Total Profit = Total Revenue - Total Cost _____________