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ECONOMIC INSTRUCTION

The Pollution Game: A Classroom Game Demonstrating the Relative Effectiveness of Emissions Taxes and Tradable Permits

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This classroom game illustrates the strengths and weaknesses of various regulatory frameworks aimed at internalizing negative externalities from pollution. Specifically, the game divides students into three groups—a government regulatory agency and two polluting firms—and allows them to work through a system of uniform command-and-control regulation, a tradable emissions permit framework, and an emissions tax. Students observe how flexible, market-oriented regulatory frameworks can outperform inflexible command-and-control. More important, given the ongoing debate about how best to regulate carbon dioxide emissions, students also can observe how the introduction of abatement-cost uncertainty can cause one market-oriented solution to outperform another.

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JEL codes *A20, Q52, Q53, Q54, Q58*

Students in introductory and environmental economics courses learn that government regulators can employ policies such as uniform regulation, emissions taxes, and tradable emissions permits in response to the negative externalities from pollution. Although students learn that flexible, market-oriented policy options have the potential to produce more efficient outcomes, textbooks generally include little discussion of the relative strengths of various market-oriented frameworks.

This classroom game illustrates the efficiency gains from various government policies aimed at internalizing negative externalities, as well as problems that arise due to heterogeneous abatement costs, asymmetric information, and strategic behavior on the part of the regulated firms. While other games demonstrate different policies that regulators can use to internalize negative externalities (e.g., Bergstrom and Miller 1999, Hazlett and Bakkensen 2005), none specifically highlight the distinct regulatory challenges these policies present.

In the absence of uncertainty about abatement costs, tradable permits and emissions taxes should be equally effective at bringing about the optimal level of pollution abatement. And unlike uniform command-and-control regulation, this result holds even if firms have heterogeneous abatement costs. A point that is more difficult to convey in undergraduate courses, but that is at least as important given the current debate over how governments should regulate carbon dioxide (CO_2) emissions, is how well we can expect tradable-permit and emissions tax schemes to perform relative to one another if abatement costs are uncertain. This uncertainty could come from several sources. For example, suppose polluters have perfect information regarding their abatement costs, but have a strategic incentive to either over- or understate these true costs. In this case, the regulator will receive an imperfect signal of true abatement costs.

If regulators overestimate the true marginal cost of abatement under an emissions tax framework, they will set the tax rate undesirably high. And if, as McKibbin and Wilcoxen (2002) argue, the marginal benefit of CO_2 abatement in a given year is flat, while the marginal cost increases rapidly, this higher tax rate leads to a modest level of overabatement and a modest deadweight loss. On the other hand, if regulators overestimate the true marginal cost of abatement under a tradable-permit framework, they will issue an undesirably large number of permits. Under the same marginal-benefit and marginal-cost assumptions, this leads to a substantial level of underabatement and a deadweight loss much larger than that under a tax.[1]

PROCEDURES

The game takes about 50 minutes. It will work in classes with as few as three students or as many as 100, but the ideal class size is probably between 15 and 30 students.[2] The game, while designed primarily for undergraduate environmental economics courses, can be used in any public policy, environmental studies, or economics course that covers environmental regulation. The game is intended for students who have at minimum been introduced to the concepts of marginal analysis and externality. Students do not necessarily need to have been exposed to formal models of emissions taxes and tradable permits, but if they have not, the instructor will need to briefly explain the optimal strategies under each regime (i.e., the per-ton tax rate should equal the marginal benefit from abatement at the optimal level of pollution, and the number of permits issued should equal the optimal level of pollution).

The instructor begins by dividing the class into three groups of roughly equal size—the government regulatory agency, Ace Energy, and Deuce Petrochemical—giving each student in each group the appropriate instruction sheet. Condensed versions of these instructions are included in the appendix.[3] Note that Deuce's abatement costs are twice Ace's costs.

In the game's first phase, the focus is on the government regulatory agency. The regulator's goal is to bring about the socially optimal level of abatement, while minimizing cost to industry.[4] The regulator's handout provides information about the social benefit associated with abatement (and, by extension, the social damage caused by pollution). The firms' abatement costs, however, are private information available only to a given firm. The regulator can ask each firm questions about its abatement cost structure (e.g., "What's your total cost of reducing pollution by 10 tons?" or "What's the additional cost of the 10th ton of abatement?"), although firms are free to respond strategically.[5] While this questions-and-answers stage can be as structured or as informal as an instructor chooses, one effective strategy is to instruct the regulator to come up with a fixed

number of questions (e.g., four) that it will write on the board with the understanding that both firms will then answer these and only these questions. Experience suggests that both firms will likely overstate their abatement costs. Astute regulators will recognize this and do their best to compensate.

Once the regulator has arrived at its best estimate of the optimal level of abatement, it simultaneously constructs three distinct pollution control schemes: (1) a uniform command-and-control framework requiring both firms to reduce emissions by the same amount; (2) a cap-and-trade framework where the regulator makes available a fixed number of pollution permits; and (3) an emissions tax framework where each firm has to pay a fixed dollar amount for each ton of pollution it chooses to generate.

In the game's second phase, attention turns to the polluting firms. The firms begin by choosing their level of abatement in response to the regulator's command-and-control regulation. This is straightforward because both firms are instructed to reduce emissions by the same amount. Each firm then calculates (but does not reveal) the total cost of compliance with this regulatory structure, and the regulator announces the total benefit that society derives from abatement. Finally, the instructor announces the extent of the deadweight loss under command-and-control regulation. Note that it is important that the instructor not announce at this stage whether the deadweight loss is the result of too much pollution, too much abatement, or simply a misallocation of abatement across firms. This would take away some of the suspense from later regulatory rounds and might give a firm information about its rival's abatement cost structure.

In the second regulatory round, the regulator allocates tradable emissions permits to firms. At the instructor's discretion, these permits either can be auctioned off or given away to firms for free. In the former case, an ascending-price English auction works well and should be familiar to students. The instructor starts by naming a low selling price (e.g., $5 per permit) and then raises the price incrementally until one firm drops out of the auction. In the interest of time, the instructor may want to start by auctioning off a bundle of five permits and then auction subsequent permits individually. If permits are to be given away, the instructor also should allow firms to trade permits informally. Here, each firm might select one student to bargain over the price and quantity of permits bought from or sold to the competing firm. These deliberations are made openly so that everyone in class can observe. The instructor could encourage these two students to begin their bargaining with questions like "What's the lowest price you'd be willing to sell one permit for?" or "What's the highest price you'd be willing to pay for five permits?" Both bargainers are, of course, free to respond to these questions strategically, though a few minutes of negotiating generally allows students to reach some kind of agreement. The instructor may wish to limit these negotiations to five minutes to keep the game moving.

Once permits are allocated, the regulator again announces the total benefit from abatement, and firms calculate the total cost of compliance net any proceeds from permit sales or purchases. The instructor then announces the deadweight loss for this second regulatory round.

Deadweight loss under permits generally will be less than that under command-and-control regulation unless permits were allocated very poorly at the end of the permit negotiations or the regulator chose to allow a less-optimal quantity of pollution than in the command-and-control round. To help students understand why this market-oriented framework outperforms command-and-control, the instructor can ask the firms to announce their total abatement costs under both the command-and-control and cap-and-trade regulatory frameworks. Assuming the regulator settled on the same level of pollution under both schemes, the total level of abatement (and therefore

total damage from pollution) will be the same in both rounds, but introducing a market for permits allows industry to achieve a given level of abatement at lower cost.

In the third, and final, regulatory round, firms respond to the emissions tax set by the regulator in the game's first phase by choosing a level of abatement that minimizes compliance costs, in this case defined as abatement costs plus total emissions taxes paid. This should be a straightforward application of the equimarginal principle (i.e., firms abate so long as the cost of one more ton of abatement is less than or equal to the cost of paying the emissions tax). Experience suggests, however, that students may need a gentle reminder. Once both firms have determined their optimal abatement levels, they can announce what these levels are along with their total compliance costs. The regulator again calculates and announces the total benefit from abatement, and the instructor announces the deadweight loss. The marginal-cost and -benefit schedules from the appendix are structured such that the marginal cost of abatement is the steeper of the two curves. With this in mind, the deadweight loss from this third regulatory round will likely be the smallest of the three rounds.

DISCUSSION

This game can generate a rich class discussion. To begin, the instructor may use the game to highlight the predictions and assumptions of economic theory. For instance, experience suggests that both market-oriented frameworks will outperform the uniform command-and-control standard. Students should be able to see that this is due to the market-oriented frameworks' flexibility in dealing with heterogeneous abatement costs. More formally, table 1 details the marginal-benefit and aggregated marginal-cost schedules from the appendix. The marginal benefit and marginal cost of abatement are equated when industry reduces pollution by 18 tons, with low-cost Ace

TABLE 1
Marginal-Benefit and Marginal-Cost Schedules

Tons of pollution abated	Marginal benefit	Marginal cost	Firm abating	Tons of pollution abated	Marginal benefit	Marginal cost	Firm abating
1	$65	$4	Ace	16	$50	$44	Ace
2	$64	$8	Ace	17	$49	$48	Ace
3	$63	$8	Deuce	18	$48	$48	Deuce
4	$62	$12	Ace	19	$47	$52	Ace
5	$61	$16	Ace	20	$46	$56	Ace
6	$60	$16	Deuce	21	$45	$56	Deuce
7	$59	$20	Ace	22	$44	$60	Ace
8	$58	$24	Ace	23	$43	$64	Deuce
9	$57	$24	Deuce	24	$42	$72	Deuce
10	$56	$28	Ace	25	$41	$80	Deuce
11	$55	$32	Ace	26	$40	$88	Deuce
12	$54	$32	Deuce	27	$39	$96	Deuce
13	$53	$36	Ace	28	$38	$104	Deuce
14	$52	$40	Ace	29	$37	$112	Deuce
15	$51	$40	Deuce	30	$36	$120	Deuce

reducing its pollution by 12 tons, while high-cost Deuce reduces its pollution by just six tons. Using the total benefit and total cost figures from the appendix, this level of abatement brings about $1,017 in total benefits at a total cost to industry of just $480—yielding a substantially greater net benefit than if both firms were forced to reduce pollution by a uniform nine tons.

Students also may discover that market-oriented frameworks can lead to a cost-effective solution even if the government chooses an inefficient tax level or number of permits. For example, facing a tax rate of $24 per ton (half of the efficient level), low-cost Ace should still reduce its pollution by twice as much as high-cost Deuce. The same should hold if the government auctions off 24 permits instead of the optimal 12. This is especially pertinent given that pollution targets are in practice influenced as much by political expediency as by economic efficiency (Joskow and Schmalensee 1998).

This game also can highlight the difference between the market-oriented abatement frameworks. For example, astute students will realize that tax and permit schemes present different incentives for firms to strategically misrepresent abatement costs. Firms have an incentive to understate their marginal-abatement costs in anticipation of an emissions tax because this could lead to the actual tax rate's being set below the optimal level. Conversely, firms have an incentive to overstate their marginal-abatement costs in anticipation of a permit framework because this could lead the regulator to issuing permits in excess of the optimal number. Occasionally students have recognized this at the outset of the game and have split the difference by honestly answering the regulator's questions in the game's first phase.

The game's results generally show that while both market-oriented regulatory frameworks outperform command-and-control regulation, taxes outperform permits given the built-in uncertainty and the relative slopes of the marginal-benefit and -cost curves. For example, if the regulator were to overestimate marginal-abatement cost by a factor of two, table 1 suggests that it would require each firm to reduce pollution by five tons under the command-and-control framework, that it would issue 20 permits under the cap-and-trade framework, and that it would set a $56 per-ton emissions tax. Command-and-control framework would yield 10 tons of abatement and $425 in net benefits (a $112 deadweight loss relative to the efficient outcome). Tradable permits would yield 10 tons of abatement and $445 in net benefits (a $92 deadweight loss relative to the efficient outcome). And a tax would yield 21 tons of abatement and $511 in net benefits (just a $26 deadweight loss relative to the efficient outcome).

Although this result can be shown graphically, grasping the intuition can be challenging for students. A few minutes of discussion should help students to see that when marginal-abatement costs are initially low but then increase quickly, placing an inflexible cap on emissions through permits, on the one hand, can lead to situations where the marginal cost of the last ton of abatement is dramatically greater than or less than the marginal benefit from that last ton. Placing an upper limit on marginal-abatement cost by using a tax, on the other hand, allows firms to pollute more or less than regulators originally envisioned, which in this scenario can lead to a more efficient outcome.

The instructor should stress, however, that taxes will not always outperform permits. The regulatory framework likely to yield the more efficient outcome depends critically on the nature of the pollutant and the associated abatement technology. McKibbin and Wilcoxen (2002) argue that because of the long-lived nature of CO_2 in the atmosphere, the marginal damage from CO_2 emissions in any given year (or, alternatively, the marginal benefit from CO_2 abatement) is roughly constant. The marginal cost of abatement in any given year, on the other hand, increases

rapidly as firms and households quickly exhaust low-cost abatement alternatives (e.g., switching to compact-florescent light bulbs) and have to turn to more-expensive technologies (e.g., by replacing electricity from coal-fired power plants with more expensive renewable energy). Under these assumptions, a tax will generally outperform permits from an efficiency standpoint.

In other cases, permits will outperform a tax. In the case of sulfur dioxide (SO_2) emissions linked to respiratory illness and acid rain, for example, the marginal damage from emissions in any given time period increase rapidly as ground-level SO_2 concentrations cross the threshold for human safety (Chestnut and Mills 2005). The marginal cost of abatement, in contrast, is relatively flat given that the primary means for reducing SO_2 is switching to low-sulfur coal from Utah's Powder River Basin (Schmalensee et al. 1998).

The instructor also may ask students to think about the extent to which the ordering of rounds influenced outcomes. For example, did command-and-control framework underperform the market-oriented approaches simply because it was the first regulatory regime that firms encountered? What, if anything, did firms learn in the command-and-control framework and permit rounds that they could have used to gain a strategic advantage in the final tax round?

Finally, the instructor may wish to spend a few minutes on the nature of uncertainty in this exercise and in environmental policy more generally. Here, polluters had perfect information about their abatement costs, but the regulator received only an imperfect signal of those costs. In reality, it is more likely that no party will have perfect information. For example, in the case of CO_2 emissions, it is impossible to predict with any certainty what abatement technologies will be available in 10 years, let alone how much those technologies will cost to implement. Season-to-season temperature fluctuations will influence the demand for heating fuels, affecting the cost of achieving any given emissions target. The benefits of CO_2 abatement also are necessarily uncertain given the vagaries of forecasting the climate decades into the future. This is not necessarily an argument against regulation, but policy makers should be aware of the ways in which different regulatory frameworks perform in the presence of uncertainty.

Instructors have a wealth of additional readings to choose from regarding market-oriented pollution control frameworks, especially as they relate to SO_2 and CO_2 emissions. Schmalensee et al. (1998) and Stavins (1998) provide brief, accessible overviews of the economics of SO_2 allowance trading. McKibbin and Wilcoxen (2002) discuss the strengths and weaknesses of tax and permit frameworks as they relate to CO_2 emissions from both the standpoint of economic theory and that of political economy. Instructors interested in a more popular take on the tax-versus-permit debate might consider Mankiw's (2006) op-ed in the *Wall Street Journal* and Stavins's (2008) op-ed in the *Boston Globe*.

NOTES

1. Figures depicting marginal benefit, marginal cost, and deadweight loss under both scenarios are available for download at http://economics.kenyon.edu/corrigan/pollutiongame/.
2. For large classes, the instructor may wish to divide students into two or more economies, each with its own regulatory agency and industries.
3. Full versions of the instructions and other useful ancillary materials are available for download at http://economics.kenyon.edu/corrigan/pollutiongame/.
4. Although the instructions are written assuming that the regulator's goal is to maximize society's overall well-being, the instructor may choose to offer the regulator the option of choosing its own objective, taking a moment to point out the strengths and weaknesses of each approach. For example, the regulator can

choose to minimize pollution, but this will impose a high cost on firms and, eventually, their customers. Conversely, the regulator may choose to maximize permit or tax revenue, although depending on the elasticity of firms' pollution demand, this may lead to either too much pollution or too little pollution relative to the socially optimal level.

5. An instructor wishing to devote more attention to strategic interaction may wish to introduce a Kwerel mechanism. Kwerel (1977) shows that when the regulator (1) issues Z' permits such that the marginal benefit from abatement equals the industry's stated marginal abatement cost, and (2) commits to buying back unused permits at a price equal to the marginal benefit from abatement at Z', firms can do no better than to accurately report their costs. This would, among other things, serve as a starting point for a discussion of the larger mechanism design literature. However, this approach also adds time and complexity to the exercise. See English and Yates (2007) for a current and accessible review of the recent literature.

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APPENDIX
INSTRUCTION SHEETS FOR THE THREE GROUPS

The Regulator

In everything you do, your goal is to maximize society's well-being. The problem in front of you right now is the regulation of air pollution generated by industry. While it's virtually impossible for firms to do business without also generating some amount of air pollution, the quantity of pollution can be controlled using any number of techniques (for example, by using inputs more efficiently or by installing abatement equipment). Your crack staff of environmental toxicologists, engineers, and economists has put together the following table [table A1] describing the benefits society derives from reducing air pollution.

You'll need to find a way to motivate firms to limit air pollution to the efficient level. You'll start by asking firms about their abatement costs (bearing in mind that they may not be entirely truthful

TABLE A1
The Regulator: Benefits That Society Derives from Reducing Air Pollution

Tons of pollution abated	Marginal benefit	Total benefit	Tons of pollution abated	Marginal benefit	Total benefit
1	$65	$65	16	$50	$920
2	$64	$129	17	$49	$969
3	$63	$192	18	$48	$1,017
4	$62	$254	19	$47	$1,064
5	$61	$315	20	$46	$1,110
6	$60	$375	21	$45	$1,155
7	$59	$434	22	$44	$1,199
8	$58	$492	23	$43	$1,242
9	$57	$549	24	$42	$1,284
10	$56	$605	25	$41	$1,325
11	$55	$660	26	$40	$1,365
12	$54	$714	27	$39	$1,404
13	$53	$767	28	$38	$1,442
14	$52	$819	29	$37	$1,479
15	$51	$870	30	$36	$1,515

in their responses). Once you come up with your best guess of abatement costs, you can determine the optimal level of emissions. With this number in mind, you'll need to determine (1) a uniform abatement standard you'd apply under a command-and-control framework, (2) the number of permits you'd issue under a tradable-emissions-permit framework, and (3) the per-ton tax you'd impose under an emissions-tax framework.

Remember that you're interested in society's well-being, which includes the well-being of polluting firms. So when you're devising your pollution-control strategies, you'd like to find some way to arrive at the efficient level of pollution while imposing the lowest possible costs on industry.

Ace Energy

Your goal at Ace is really, really simple: You want to maximize profits. You don't care about trees or flowers or dolphins or anything else. All you want to do is to make the most money you possibly can. On the way to achieving that goal, you want to spend as little as possible on pollution abatement.

Left on your own, you'd generate 15 tons of air pollution every year, though you can reduce that amount by pursuing costly abatement. Your pollution abatement costs are detailed below [table A2]. The government regulator will ask you questions about these costs and use your answers to design three different pollution control policies. You're free to over- or understate your true costs if you think that's in your best interest.

Deuce Petrochemical

Your goal at Deuce is really, really simple: You want to maximize profits. You don't care about trees or flowers or dolphins or anything else. All you want to do is to make the most money you possibly can. On the way to achieving that goal, you want to spend as little as possible on pollution abatement.

TABLE A2
Ace Energy's Pollution Abatement Costs

Tons of pollution abated	Marginal abatement cost	Total abatement cost
1	$4	$4
2	$8	$12
3	$12	$24
4	$16	$40
5	$20	$60
6	$24	$84
7	$28	$112
8	$32	$144
9	$36	$180
10	$40	$220
11	$44	$264
12	$48	$312
13	$52	$364
14	$56	$420
15	$60	$480

Left on your own, you'd generate 15 tons of air pollution every year, though you can reduce that amount by pursuing costly abatement. Your pollution abatement costs are detailed below (table A3). The government regulator will ask you questions about these costs and use your answers to design three different pollution control policies. You're free to over- or understate your true costs if you think that's in your best interest.

TABLE A3
Deuce Petrochemical's Pollution Abatement Costs

Tons of pollution abated	Marginal abatement cost	Total abatement cost
1	$8	$8
2	$16	$24
3	$24	$48
4	$32	$80
5	$40	$120
6	$48	$168
7	$56	$224
8	$64	$288
9	$72	$360
10	$80	$440
11	$88	$528
12	$96	$624
13	$104	$728
14	$112	$840
15	$120	$960