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# Teaching Opportunity Cost in an Emissions Permit Experiment

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## Abstract

This paper describes an individual choice experiment that can be used to teach students how to correctly account for opportunity costs in production decisions. Students play the role of producers who require a fuel input and an emissions permit for production. Given fixed market prices, they make production quantity decisions on the basis of their costs. Permits have a constant price throughout the experiment. In one treatment, students have to purchase both a fuel input and an emissions permit for each production unit. In a second treatment, they receive permits for free, and any unused permits are sold on their behalf at the permit price. If students correctly incorporate opportunity costs, they will have the same supply function in both treatments. This experiment motivates classroom discussion of opportunity costs and emissions permit allocation under cap-and-trade schemes. The European Union Emissions Trading Scheme provides a relevant example for classroom discussion, as industry earned significant windfall profits from free allocation of emissions allowances in the early phases of the program.

**Key Words:** opportunity cost, emissions permits, allowance allocation, classroom experiments

**JEL Classification Numbers:** A22, C90, Q52

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## Introduction

The notion of opportunity cost is pervasive in economics, and it is one of the first “principles” encountered by students in an introductory microeconomics class. A typical example is given in terms of the alternative earnings potential of a self-employed manager or farmer, in which the accounting profit of the business can be converted into an economic loss when the opportunity cost of self-employment is considered. Most students readily agree with the reasoning in this example, and yet experience with simulations of actual decisions reveals that many of them fail to incorporate opportunity costs into other decisions correctly. This paper presents a class experiment in an environmental frame in which interpersonal earnings comparisons can be used to show that those with low earnings can improve their earnings dramatically by basing decisions on a correct cost measure that includes opportunity cost. The key insight is that if tradable permits for greenhouse gases or other emissions are provided free to producers in a process called “grandfathering,” then the producer’s cost should include the opportunity cost of the permits, which is what they can sell for in an open market. This experiment takes about 30 minutes to run, and about 15 minutes should be allocated to discussion. It can be used for courses in introductory and intermediate microeconomics as well as courses in environmental economics.

## Procedures

The experiment can be run by hand by providing students with a table of variable fuel costs for each of their capacity units and by giving them endowments of permits and telling them what unused permits can be sold for in an external permit market. The students then decide whether to operate each of their capacity units at a market price for the product that is announced

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by the instructor. The process can be repeated several times with different market prices to obtain points on a supply function, and earnings can be compared so that students can see that the person with the highest earnings had a supply function that is shifted up due to the opportunity cost of the grandfathered permits being “built in.” Instructions for the hand-run version can be brief:

You are a producer with 3 capacity units, shown in column (1) of the table. You require a fuel input and an emissions “permit” to produce each unit, and if you do produce a unit, you will sell the output at a price that can be entered for each of your three capacity units in column (2) when it is announced each round. For any unit that you decide to produce, you will incorporate a fuel cost shown in column (3). The first unit costs \$1 to operate (think of these numbers in terms of millions of dollars). The second capacity unit costs \$3 to operate, and the third costs \$5 to operate. You have been given, free of charge, 3 permits that must be used or sold in this production period, i.e. no banking of permits for future periods is allowed. You indicate your permit use decisions for each capacity unit by circling a 0 or a 1 in column (4). Any unused permits will be automatically sold in a national emissions permit market for a price of \$3. If you use a permit, you receive the difference between price and fuel cost, which can be entered in column (5). Your earnings for the period consist of the sum of the difference between price and cost in column (5), plus \$3 for each of your unused permits.

**Table 1. Decision Sheet for Production Period**

(1) <b>Capacity Unit</b>	(2) <b>Price</b> (at which product can be sold)	(3) <b>Fuel Cost</b>	(4) <b>Permits Used</b> (1 permit needed for each capacity unit operated)	(5) <b>Price – Fuel Cost</b> (0 if no permit used)
1st	\$	\$1	0 or 1	
2nd	\$	\$3	0 or 1	
3rd	\$	\$5	0 or 1	
	Sum of price–cost differences for units operated:			
	Earnings on unused permits sold at \$3 each:			
	Total earnings for the production period:			

For the hand-run version, the instructor will want to copy and distribute earnings tables for a number of periods and to make a template for graphing supply functions over a range of prices from 1 to 9. To avoid indifference, use prices in 50-cent increments, for example, a randomly ordered mix of prices such as \$1.50, \$2.50, \$3.50, ... \$8.50. Decision tables should be copied in advance and distributed when the instructions are read aloud.

This experiment can also be run online by using the Veconlab software.<sup>1</sup> The software provides instructions, tabulates individual decisions and earnings, and creates graphs of observed supply functions for the class as a whole, for the person with the highest earnings, and for the person with the lowest earnings. Since this is an individual decision experiment, it can either be run after hours, with students logging in from home, or in class with students who bring laptops to class (those without laptops can sit next to those with laptops). It is not necessary to pick one person randomly to receive their earnings, but if you announce that you will do so in advance, the number of laptops in class will increase dramatically. The online version also permits a wide array of setup options. In particular, there can be a second treatment without grandfathering (i.e., all permits are purchased at their market value of \$3) in which observed behavior typically conforms more closely to the theoretical supply curve.

To run the online version, you need to have internet connections, but no special software or add-ins are required. Begin by navigating to the admin menu (Google “Veconlab admin”). If not done previously, you should register and select a username and password. Students do not need to register, but when they join a session they will be assigned an identification (ID) number. The instructor username consists of several letters, (e.g., cat), and each separate “session” you run with a class will have a number appended (e.g., cat1, cat2, etc.). Select the Markets menu and click on Production Cost to begin setup. After you enter your username and password, you will see a list of sessions (if any) that you have run with previous classes. You may overwrite data in an existing session (e.g., cat3) or you may create a new session from the blank one at the bottom of the list.

On the first setup page, enter the maximum number of participants (it’s okay if fewer login) and the following selections: Number of Treatments (2), Product Market (fixed price, NOT BDM), Number of Capacity Units (3), Terminology (environmental), Entry Decision (automatic), Input A Variable Cost (deterministic), Input B Price (deterministic), Input C Cost

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<sup>1</sup> This “virtual laboratory” software was developed by Charles Holt at the University of Virginia.

(deterministic), and Product Prices (prespecified). These default settings implement a two-treatment setup with 8 decision rounds each. It is best to keep with the default setting of “go at your own pace” and to let students see each other’s earnings, identified by ID, in the second half of each treatment. There are 3 capacity units with fuel costs that match those for the handrun version above. Leave capacity costs set at 0, with a forced entry decision (meaning that their capacity is given), so that the automatic supply function graphs will apply. Product prices are set in 50-cent intervals to span the relevant range. In treatment 1, the student is endowed with 2 permits, so a third must be purchased at \$3 if 3 units are operated, and unused permits can be sold for \$3. In the second treatment, the permit endowments are set at \$0. Click through to the page where you can watch students log in. That page has a View Results button, which takes you to an aggregate results page where you can continue to watch logins, read instructions from the Instructions button, or view the supply function from the Graph button.

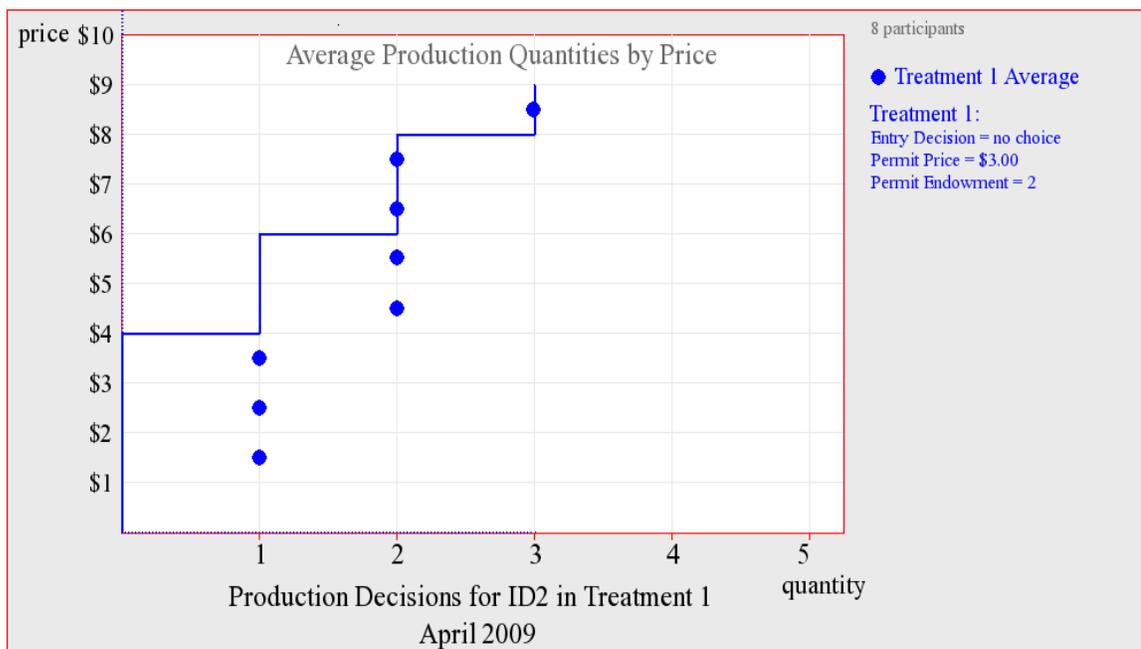
With the suggested setup defaults, the graph should show the template for a supply function; if not, it is probably because you did not set the Product Market to be “fixed price” or because you changed the capacity cost or entry settings. If you use the back arrow to adjust settings, subjects who have already logged in will have to do so again, so it is better to check the instructions and graph before class. If you set up from your office before class, you can use the View link on the admin menu and enter the session name (e.g., cat1) and your password to get to the results pages in the classroom without setting up again. Students log in from the top button on their login link (Google “Veconlab login”); all they need to know is the session name (e.g., cat1) that you used on setup, and they may select their own passwords, which would only be needed if they become disconnected and need to use the Emergency Restart button at the bottom of their login page.

As decisions are made, the results page shows the “efficiency” percentages of maximum earnings for each person’s decisions and the average efficiency by round. The graph page allows you to show or hide the supply function, and to show results for specific individuals by using the Show ID button and selecting the individual by ID. When a person has finished all rounds, the Show ID select menu lists earnings and identifies the IDs with the minimum and maximum earnings.

## Classroom Discussion

Students are typically interested in who earned the most, and a class discussion can begin with a discussion of relative earnings. If the class default settings are used, the Graph page of the Veconlab software has a select menu that lists all participant IDs and their earnings and identifies the minimum and maximum earnings. You can connect your computer to a projector in order to share the results with the class. This lets you project the supply behavior of selected individuals for each treatment, as shown in Figure 1 for a particular student (ID2) for the first treatment. This student had the lowest overall earnings for a group of intermediate microeconomics students. This person consistently supplied too many units to the market, as indicated by the dots being below the supply function, which incorporates the opportunity cost of the grandfathered permits. Of the three dots on the predicted supply function, two were at prices of \$7.50 and \$8.50, for which both of the grandfathered permits should be sold anyway, even if one failed to incorporate opportunity cost. Overall, this student only earned \$60.50, relative to the maximum earnings of \$83 achieved by those with the highest earnings. One of the most effective points to make in the class discussion is that a correct accounting for opportunity cost could have raised earnings by over 33 percent for this person. The decisions for the person with the highest earnings will typically generate dots that trace the predicted supply curve.

**Figure 1. Supply Decisions with Grandfathering of a Student with Low Earnings**



It is often easier to let students go at their own pace in a classroom experiment of this type, but the result is that the relative earnings information is not available to the first person who

makes each decision, and even the second and third people to finish may not see many other earnings results with which to make comparisons. Nevertheless, class discussion indicates that relative earnings can help some people to realize that units should not be sold below the sum of the fuel cost and the opportunity cost of a permit.

The initial allocation of allowances in the European Union Emissions Trading Scheme (EU ETS) for CO<sub>2</sub> emissions provides an illustrative example for class discussion. Note that when opportunity cost is included correctly, the supply function is the same whether or not permits are grandfathered. When the initial allocation for the EU ETS program was being discussed, one argument put forward by electric power producers was basically “if you make us pay for permits, we will end up raising the price for electricity.” You should read this argument to the students and ask them to evaluate it. If they have understood the implications of their experiment, they should conclude that the price of electricity will rise regardless of whether allocations are free (grandfathering) or made by selling permits. This is because the scarcity of permits results in a positive price for permits in the resale market, and this price is the basis of the opportunity cost of a permit. Next, ask them to evaluate the alternative of grandfathering versus permit sales on producer profits (you may want to report the average earnings in each experimental treatment if two treatments were used). Finally, you can note that the EU initially adopted a policy of grandfathering, with auctions limited to at most five percent of permits for each country. This resulted in windfall profits for producers, at least while permits remained scarce, and the result was some public dissatisfaction with the cap-and-trade system. Ensuing criticisms have led the European Commission to reconsider the use of free allocation. Plans are in place to auction most of the allowances that will be used by the power sector beginning in 2013 and to auction to most other covered emissions sources by 2020. Auctioning of emissions allowances has emerged as a key feature of most legislative proposals for climate policy in the United States. President Obama’s first proposed budget plan included revenues that would result from auctioning a majority of the allowances under a CO<sub>2</sub> cap-and-trade program.

### Further Reading

Empirical analyses show that there has been significant pass through of emissions allowance costs in the relatively competitive EU electricity markets. Bunn and Fezzi (2007) found that consumers in the U.K. electricity market pay for a significant portion of the value of emissions allowances that industry has mostly received for free. Fell (2008) analyzed the Nordic electricity market and had similar findings.

In several cases, EU governmental authorities have taken action against firms for passing through too much of the economic value of the allowances given to them for free. The German Federal Cartel Office (Bundeskartellamt) sent a warning letter<sup>2</sup> to RWE<sup>3</sup> in 2006 charging that its industrial electricity prices were abusive because the company had passed on more than 25 percent of the CO<sub>2</sub> emissions allowance value to electricity prices. More recently, the Belgian energy market regulator, CREG, stated authorities “must act to prevent utilities from making windfall profits by passing on the cost of carbon emission rights to consumers,” citing a finding that Belgian energy producers made close to 1.2 billion euros between 2005 and 2007 by charging customers for allowances that they had received for free.<sup>4</sup> The intuition that free allocation will not raise direct costs of production and therefore should not lead to higher consumer prices appears to be deeply ingrained in some members of the public, policy makers, and industry.

Wråke et al. (2009) use an individual choice experimental setup similar to the one described above to investigate students’ understanding of opportunity cost in an emissions permit market. They find that many participants do not recognize opportunity costs initially, but that they learn over time and that learning can be accelerated by relative profit information. An interesting extension in the paper was the administration of a cognitive reflection test at the end of the experiment. According to Frederick (2005), the test measures “‘cognitive reflection’—the ability or disposition to resist reporting the response that first comes to mind.” Wråke et al. (2009) find that those who earned higher profits in the experiment also performed better on the cognitive reflection test, highlighting that the concept of opportunity cost is intuitively difficult and not initially obvious to some observers.

Classroom experiments can also be illustrative for learning about market failures and externalities. Anderson and Stafford (2000) describe a classroom experiment that uses an emissions trading scheme with a double auction. Students learn that the initial allocation of property rights will not affect the efficiency of the program but will have dramatic effects on the distribution of gains and losses. Kilkenny (2000) outlines a classroom experiment that illustrates

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<sup>2</sup> See press release, December 20, 2006, at [www.bundeskartellamt.de/wEnglisch/News/Archiv/ArchivNews2006/2006\\_12\\_20.php](http://www.bundeskartellamt.de/wEnglisch/News/Archiv/ArchivNews2006/2006_12_20.php).

<sup>3</sup> RWE, one of the largest electricity producers in Germany, is subject to the EU ETS and, as all entities participating in EU ETS, has received a major share of its allowances for free according to a grandfathering procedure.

<sup>4</sup> As quoted by Thompson Reuters on January 21, 2009.

the concept of externalities and the efficiency tradable permits relative to Pigouvian taxes for internalizing those costs. She suggests a creative way to demonstrate pollution externalities by having students who have been affected wear bags on their heads.

In the experiment we describe here, students make production quantity decisions on the basis of a fixed market price. The experiment could equivalently be run with students specifying the lowest price they would be willing to accept for each production unit. As with the quantity choice environment, the market price is randomly determined. Students receive the market price for production units where their specified price is below the market price. This mechanism is known as Becker–DeGroot–Marshak (BDM) (Becker et al. 1964). Bidding along the price dimension rather than the quantity dimension is more directly analogous to electricity pricing. However, it is sometimes difficult for students to recognize that the BDM mechanism is incentive compatible; this difficulty can detract from the true goal of the lesson, which is to understand opportunity cost.

As with the notion of opportunity costs, sunk costs can also be difficult for students in beginning and intermediate microeconomics classes to account for correctly in production decisions. An interesting extension of the experiment described in this paper would be to run treatments in which there is a cost to enter the market (the setting for this is “Entry Decision”). Experiments with both sunk costs and BDM price mechanism are available by using the Veconlab software described above.

## References

- Anderson, L.R., and S.L. Stafford. 2000. Choosing Winners and Losers in a Classroom Permit Trading Game. *Southern Economic Journal* 67(1): 212–19.
- Becker, G., M. DeGroot, and J. Marschak. 1964. Measuring Utility by a Single-Response Sequential Method. *Behavioral Science* 9: 226–232.
- Bunn, D.W., and C. Fezzi. 2007. Interaction of European Carbon Trading and Energy Prices. *The Fondazione Eni Enrico Mattei Note di Lavoro Series*. Milan, Italy: Fondazione Eni Enrico Mattei, 63.2007.
- Fell, H. 2008. EU-ETS and Nordic Electricity: A CVAR Analysis. Discussion paper 08-31. Washington, DC: Resources for the Future.
- Frederick, S. 2005. Cognitive Reflection and Decision Making. *Journal of Economic Perspectives* 19(4): 25–42.
- Kilkenny, M. 2000. A Classroom Experiment about Tradable Permits. *Review of Agricultural Economics* 22(2): 586–606.
- Wråke, M., E. Myers, S. Mandell, C. Holt, and D. Burtraw. 2009. Pricing Strategies under Emissions Trading: An Experimental Analysis. Discussion paper 08-49. Washington, DC: Resources for the Future.