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The tradable pollution permit exercise: Three additional tools

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ABSTRACT

Permit trading has been a significant innovation in controlling pollution. Ando and Harrington (2006) developed a classroom exercise demonstrating the effectiveness of a tradable permits market. We provide three additional pedagogical tools. First, we show how intermediate microeconomics students can algebraically and graphically calculate the market-clearing permit price. Second, for advanced students we show how the cost-minimizing allocation of pollution control is achieved using a Lagrangian equation and explain the economic interpretation of the shadow price. Third, we show how to solve the first order conditions using Excel's matrix inverse tool for each firm's emissions reductions and the shadow price.

1. Motivation

The trading of pollution permits has been one of the significant innovations in reducing pollution in a cost-effective manner in the past two decades, and classroom experiments have emerged to help instructors present the concepts. Holt et al. (2010) describe a classroom exercise that teaches students to identify and account for opportunity costs in production decisions, allowing for a more useful classroom discussion of pollution permits. Ando and Harrington (2006) developed a highly informative classroom exercise demonstrating the efficacy of the tradable pollution permit market. Students are put into groups that represent six firms, and each firm is given a marginal abatement cost

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(MAC) curve in equation form. Initially, each firm is asked to calculate the optimal amount to abate and what the abatement cost will be under a uniform standard. Instructors can inform students that coal-fired electricity plants face this abatement problem. An excellent real-world example comes from Fowlie et al. (2012), who analyze the MAC curves for abating NOx for U.S. power plants. (NOx is a primary contributor to ozone pollution.) In the late 1990s, to enable power plants to comply with market-based NOx regulations, the Electric Power Research Institute (EPRI) constructed a software program (called "UMBRELLA") to estimate abatement costs for all major NOx control options based on unit- and plant-level characteristics. EPRI is an entity created and funded by public and private electric utilities to perform electricity-related R&D. Fowlie et al. (2012) examine fifteen different methods to control NOx, based on different boiler types and NOx technology. Thus different MAC curves are generated for 632 coal-fired generating units. Fowlie et al. (2012) horizontally sum the unit-specific MAC curves to construct an aggregate MAC curve, then vary the pollution cap to determine a range of equilibrium permit prices. Other practical examples include SO_2 abatement (Carlson et al., 2000) and SO_2 and NOx abatement (Rezek and Blair, 2005). Similarly, McKinsey & Company, an international consulting firm, is well recognized for its reports on marginal abatement costs for controlling carbon emissions (Ackerman and Bueno, 2011).

Ando and Harrington (2006) introduce a tradable permit system, with the instructor acting as a Walrasian auctioneer. By tabulating the firms' demands for permits at various prices, the instructor can show how the market clears at a particular price. Firm-and industry-level total abatement, cost of abatement, and cost net of revenue from permit sales can be tabulated.

While the Ando and Harrington (2006) exercise is very effective, a few simple enhancements make it even more engaging and useful as a pedagogical tool, particularly for more advanced students. First, as it stands, the equilibrium price is essentially determined by trial and error. This is an appropriate approach for explaining the process to students with limited backgrounds in Economics. However, students who have completed intermediate microeconomics can be shown how to calculate algebraically the equilibrium market-clearing tradable permit price and can be shown how to display graphically the equilibrium. Second, the more advanced students (e.g., students who have taken mathematical economics) can be shown how the cost-minimizing allocation of pollution control is achieved using a Lagrangian equation and how to interpret the shadow price (which is equal to the market-clearing price). Third, the more advanced students can be shown how to solve computationally the Lagrangian first order conditions using Excel's matrix inverse tool to calculate the amount of emissions reductions for each firm and the value of the shadow price.

2. Calculating equilibrium permit prices

The firm's MAC curve (which is often expressed as an increasing function of abatement) is essentially the inverse demand curve for pollution permits. At lower permit prices, the firm's quantity of permits demanded will increase, implying that their quantity abated will decrease, and vice versa. Having explained this concept, instructors can demonstrate how to sum the firms' MAC curves horizontally in order to derive the industry-level MAC_{total} curve, which is essentially the inverse industry demand for pollution. Students will recognize the horizontal summation concept from their intermediate microeconomics course text (e.g., Pindyck and Rubinfeld, 2013, p. 128). This technique is useful in other applications (e.g., summing individuals' demand curves in order to create a market demand curve), so it may be worthwhile for instructors to review this method. Having completed this exercise we can equate the MAC_{total} curve to the perfectly inelastic supply of permits to calculate the equilibrium price, both algebraically and graphically.

The background information about the six firms is given in Table 1.

It should be noted that MAC curves can be expressed in one of two ways, either as a function of emissions (E) or as a function of emissions abated (q). Frequently, the MAC curve is shown as an increasing function of emissions reductions. However, in the Ando and Harrington (2006) model, the MAC curve is expressed as a downward sloping function of tons of emissions (E), not emissions reductions (q). In Ando and Harrington (2006) formulation, at higher levels of emissions, the marginal cost to abate a unit of pollution is lower. For example, for firm 1, its MAC curve can be expressed as