ELSEVIER

Ecological Economics 11 (1994) 213-226

ECOLOGICAL ECONOMICS

An experimental analysis of the effectiveness of an environmental assurance bonding system on player behavior in a simulated firm

Laura Cornwell *, Robert Costanza

Maryland International Institute for Ecological Economics, Center for Environmental and Estuarine Studies, University of Maryland, Solomons, MD 20688, USA

Received 30 March 1993; accepted 4 January 1994

Abstract

It has long been recognized that the present command and control methods for pollution abatement are inefficient. Using market mechanisms for environmental management is a promising alternative to the direct regulatory approach. Market mechanisms are just beginning to appear in U.S. environmental policy. For example, tradable permit schemes are being developed and implemented for some air pollutants under the amended Clean Air Act. Various other forms of taxes and tradable permits have been proposed; however, these systems do not address the large uncertainty inherent in most environmental problems. One mechanism currently being studied to address uncertainty more effectively is a flexible environmental assurance bonding system, designed to incorporate environmental criteria and uncertainty into market incentives. This study uses an experimental approach, employing an interactive computer game/simulation model with human players to examine the effectiveness of the assurance bonding system under varying degrees of uncertainty. An environmental cost efficiency index (ECEI), or profit per unit waste, is used to measure player performance. Preliminary results indicate that players are more successful under the assurance bonding system, in terms of ECEI, than under the simulated current system.

Keywords: Assurance bonding system; Simulation model

1. Introduction

1.1. Background

Prior to the 1960s environmental policy in the United States was based upon Riparian Rights and English common law. Those resources not under preservation protection by the government were open access, free and available to all. The result was over exploitation of the environment and the "tragedy of the commons" (Hardin, 1968). With the environment's declining condition through the 1960s and the increase of public awareness through publications such as Rachel Carson's *Silent Spring* (1962) and Kenneth Boulding's *The Economics of the Coming Spaceship Earth* (1966), the environment's status changed to that of a scarce and valuable resource. Legisla-

* Corresponding author.

SSDI 0921-8009(94)00006-H

tion through the 1970s set ambitious goals for environmental protection with fixed emission limits for individual sources based largely on specified abatement technologies (command and control strategies) to impose immediate controls on relatively few, widespread, problematic pollutants. Since this landmark legislation, much has been learned about the effectiveness of this type of environmental regulation. Economic analysis indicates that present methods of pollution control are inefficient and provide disincentives for directing resources toward abatement. For policy to be both effective and efficient, steps need to be taken to make it privately optimal to manage waste in a socially optimal manner.

1.2. Direct regulation vs. market alternatives

The traditional command and control regulatory system is inefficient because it treats firms homogeneously, both in their production process and geographic location (cf. Atkinson and Tietenberg, 1982; Seskin et al., 1983). It also places a tremendous information burden on the appropriate regulatory agency (Hahn and Noll, 1983). Under command and control, the agency is responsible for determining the best available technology for each industry, setting emissions levels for polluting substances, and monitoring and imposing penalties in cases of noncompliance. Direct regulation guides polluters towards irresponsible pollution abatement in several ways. Because it is based on a particular abatement technology, it provides no incentives for development of innovative technology; it promotes avoiding regulatory detection rather than regulatory compliance; and, because it places stricter controls on new plants and processes, it provides disincentives for growth and facility upgrade (cf. Ackerman and Stewart, 1985).

Optimization of pollution abatement requires that all costs and benefits associated with the activity be identified (Freeman, 1990). Polluters respond to direct regulation by comparing the (often) substantial costs of installing and operating abatement equipment with the uncertain costs associated with penalties for noncompliance. Uncertainty arises with respect to detection, amount of damages, liability, clean-up costs, enforcement, potential legal action, and amount of time the polluter is responsible for their emissions (cf. Peles and Stein, 1976; Roberts and Spence, 1976; Harford, 1987). These uncertainty factors can translate into incentives for resource exploitation. In addition, legislative language is often so vague that a firm can present a legally convincing case that the regulatory agency's abatement requirements are unfeasible. The polluter can further expect to negotiate a new compliance schedule with a regulatory agency which is resource limited and often more willing to gain minimal compliance than enter into lengthy and expensive legal battles (cf. Ackerman and Stewart, 1985).

In the past two decades, there has been exhaustive discussion in the literature of the efficiency that can theoretically be achieved in pollution abatement through the use of market mechanisms (cf. Tietenberg, 1973, 1985; White, 1976; Common, 1977; Kohn, 1977; Beavis and Walker, 1979; Burrows, 1979; Bohm, 1981; Marquand, 1981; Endres, 1983; Krupnick et al., 1983; Koenig, 1984; Lee, 1984; Haas, 1985; McHugh, 1985; Stollery, 1985; Webber and Webber, 1985; Brooks and Heijdra, 1987; Conrad, 1987; Costanza, 1987a; Katzman, 1987; Perrings 1987, 1989; Shaw et al., 1987; Baumol and Oates, 1988; Hahn and Hester, 1989; Hamilton et al., 1989; Milliman and Prince, 1989; Pethig and Fiedler, 1989). Some market alternatives that have been suggested include pollution taxes, tradable pollution discharge permits, financial responsibility requirements, and deposit-refund systems. Tradable permits have been included in the most recent amendments to the Clean Air Act.

The efficiency that market mechanisms can achieve for pollution abatement has been well studied both theoretically and empirically (cf. Krupnick 1983; Seskin et al., 1983). For example, studies in the St. Louis metropolitan area indicate that the existing command and control systems for air pollution abatement cost three to five times as much as an optimal incentive based approach that would yield the same ambient air quality (Atkinson and Lewis, 1974, 1976; Atkinson and Tietenberg, 1982). In reality, policy structure is more complex than some analysis would suggest. The instrument that we are suggesting should be considered along with other regulatory tools that offer flexibility.

1.3. Assurance bonding

Uncertainty is not thoroughly addressed in environmental policy despite its importance and pervasiveness in environmental problems. An innovative policy currently being studied is a flexible environmental assurance bonding system designed to incorporate environmental criteria and uncertainty into the market system, and to induce innovative environmental technology. This variation of the deposit refund system is designed to incorporate both known and uncertain environmental costs into the incentive system and to induce positive environmental technological innovation (Costanza and Cornwell, 1992). The assurance bonding system has been discussed elsewhere in the literature (Costanza, 1987a; Perrings, 1989; Costanza and Perrings, 1990; Farber, 1991; Costanza and Cornwell, 1992) and is not the topic of this paper; however, a brief overview of the principles involved is warranted.

The environmental assurance bonding system requires those seeking to use society's resources to post a bond equal to the worst-case damages they could inflict on the environment, in advance of any activity. Worst-case damage scenarios would be established by the regulatory authority with the best information available and with the advice of independent scientists. If resource users could demonstrate that damages to the environment were less than the amount of the bond (over a predetermined length of time, specified in the bond), this difference and a portion of earned interest would be refunded. Thus, the environmental assurance bonding system insures that the funds available for protecting the environment are equal to the potential harm facing its resources.

If damages did occur, the bond would be used to rehabilitate or repair the environment, and possibly to compensate injured parties. By requiring the users of environmental resources to post a bond adequate to cover potential future environmental damages (with the possibility for refunds), the burden of proof (and the cost of that burden) is shifted from the public to the resource user, and a strong economic incentive is provided to research the true costs of environmentally damaging activities and to develop innovative, cost-effective pollution control technologies. Assurance bonding is an extension of the "polluter pays" principle to "the polluter pays for uncertainty as well" or the "precautionary polluter pays principle" (4P) (Costanza and Cornwell, 1992).

Neither the principle nor the instrument proposed are new. The environmental bond has its roots in the "material use fees" first proposed by Mill (1972) and Solow (1971), the simplest working example of which is the refundable deposit on glass bottles. The aim of the deposit is to encourage the users to dispose of the commodity in the most desirable way (by recycling) and to avoid its disposal in the least desirable way (as litter). The deposit may not be sufficient to cover the cost of the worst possible method of disposal, but it is generally set at a level high enough to make returning the bottle privately profitable. The important feature of the fee is that by insisting that consumers pay *in advance* for the costs they *might* inflict on society if they adopted the most harmful method of disposal, it reverses the usual presumption of "innocence" over "guilt" as applied to environmental damages. The innocent-until-proven-guilty argument is not applicable in the case of firms using societal resources as receivers of privately generated waste since there is no question that the act is being committed. It is the amount of damage that is uncertain, and it is our contention that society should not bear this risk.

In the U.S., examples of bond use for environmental policy are few. Where they do appear in legislative language, they are generally one of several financial mechanisms available to firms that are required to demonstrate financial responsibility. There are three examples where bonds are required: Owners and operators of underground injection wells are required to post bonds to ensure proper plugging and abandonment of wells. Bonds are currently required by companies leasing public land for oil and gas exploration/extraction to ensure proper capping of wells and restoration of lands or surface waters after the cessation of the lease operations. Finally, bonds must be posted by logging companies to use existing roads on public lands for the transport of timber.

Costanza and Perrings (1990) categorize the current command and control system using the "social trap" paradigm (Platt, 1973; Cross and Guyer, 1980; Costanza, 1987a). Several experimental games have been designed to study behavior in social traps. The already-mentioned "tragedy of the commons" is a trap used to study resource exploitation (Edney and Harper, 1978). The well-known "prisoner's dilemma" game is an externality trap that has been used to study the evolution of cooperation (Axelrod, 1984), and more recently, the dollar auction game, an investment trap, was used to study the effect of taxation on the conflict escalation process (Costanza and Shrum, 1988). For this study, an experimental firm management game was developed that measures player behavior and performance while making management decisions in a theoretical firm, under both the command and control regulatory system and the assurance bonding system.

2. Methods

The purpose of this experiment was to determine the effect of two charge systems on individual behavior, under varying degrees of uncertainty. This was accomplished by developing a game designed for one player who manages a computer-simulated company by controlling production level and amount of resources devoted to waste reduction. As previously mentioned, several models of the profit-maximizing firm have been constructed to examine the effectiveness of pollution abatement using market mechanisms, and several have considered the importance of uncertainty (cf. Averch and Johnson, 1962; Weitzman, 1974; Adar and Griffin, 1976; Fishelson, 1976; Roberts and Spence, 1976; Baron and Taggart, 1977; Magat, 1978; Mendelsohn, 1984; Harford, 1987; Plourde and Yeung, 1989; Farber, 1991). None, however, have included the "experimental" aspect addressed in this paper. We believe that the experimental approach is a necessary component of the analysis because it can better address the incentives of the regulatory system without dependence on (potentially flawed) theoretical models of individual response. This experimental approach consisted of four stages: model development, game programming, data generation by human volunteers, and finally, data analysis.

2.1. The model

The model was designed using STELLA® (Structured Thinking Experimental Learning Laboratory with Animation), a software package developed by High Performance Inc. for the Apple Macintosh (cf. Costanza, 1987b). Smith and Williams (1992) recently used simulated markets to analyze the principles that govern trading decisions; however, as far as we know, our study is the first *dynamic*, interactive simulation model examining pollution abatement systems. Model development occurred in stages, with model behavior observed at each stage. Values and units in the model are arbitrary. The model is not intended to simulate any particular industry, but instead examines relative behavior and the impact of the human player's decisions.

As with all models, this one is a trade-off between realism, precision, and generality. Upon initial inspection of the model diagram (Fig. 1), it may appear quite complex. However, upon further examination of the model symbol definitions (Appendix 1), it can be seen that the model is really quite basic. Two of the seven state variables, Cum Env Damages and Acc Env Fnd, are merely accounting components that have no outflows and no external variables. The model was made as simple as possible while including those components the authors felt were minimally necessary to simulate the workings of a firm under two environmental policy regimes. The final version includes 7 state variables (boxes in Fig. 1), 8 input flows, 7 output flows (double-lined arrows with valves in Fig. 1), and 25 auxiliary variables (circles in Fig. 1). Flows of money, products, and wastes are shown by double-lined arrows while flows of information are indicated by single-lined

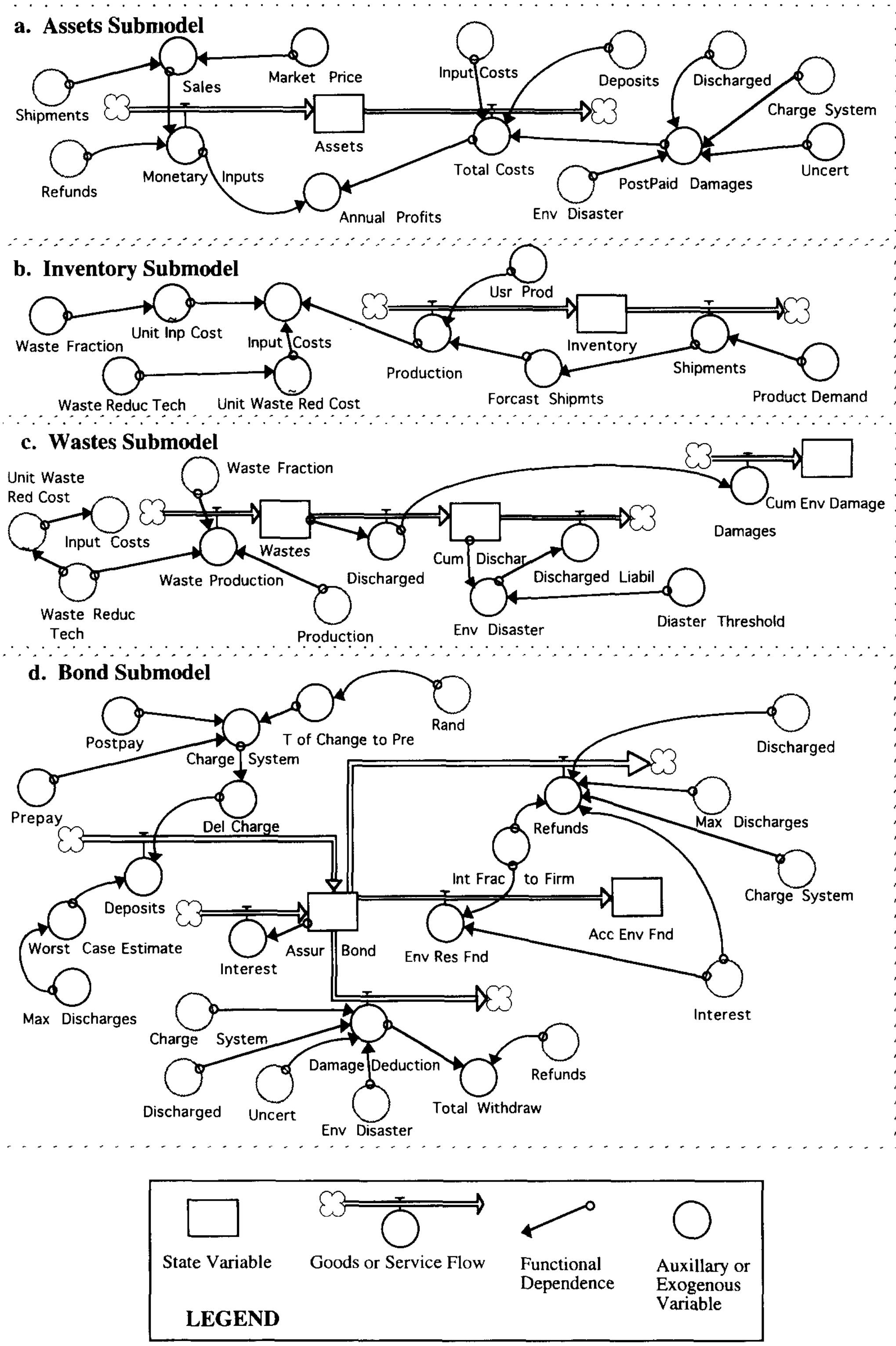


Fig. 1. Diagram of the STELLA Model. including four submodels.

arrows. Symbol definitions are given in Appendix 1. The model is composed of four connected submodels depicting firm assets, company inventory, level of wastes, and the assurance bond.

The Assets stock is incremented by flow from monetary inputs and decremented by outflow to total costs (Fig. 1a). Monetary inputs include sales based on market price and number of shipments as well as refunds from the bond. Total costs are the sum of total input costs, assurance bond deposits made during the prepay charge system, and environmental damages paid during the postpay charge system, including a randomly generated uncertainty component. Uncertainty enters into the model through payments for environmental damage. Uncertainty is a random number between 0 and 1 and affects the amount a player must "pay" for a given amount of environmental wastes. Paying variable amounts for the same level of environmental wastes represents the aforementioned uncertainty that arises with respect to detection, amount of damages, liability, clean-up costs, enforcement, potential legal action, and amount of time the polluter is responsible for their emissions.

The stock of inventory is based on inputs from production and outputs to shipments (Fig. 1b). Shipments are based on a randomly generated product demand that forecasts five years into the future. The cost of inputs for production is the sum of unit costs for inputs and waste reduction technology multiplied by the amount of production. As the level of production increases, so do the costs associated with inputs to attain that level.

Stocks of waste are based on by-products of production and discharge (Fig. 1c). Waste production is simply a function of the level of firm production and the amount of resources devoted to waste reduction technology. Waste reduction technology can improve efficiency by decreasing the waste fraction (i.e., by recycling or by using new technology). As wastes are released into the environment, they accumulate as a stock of discharge. This discharge, in turn, determines the stock of cumulative environmental damage. Environmental disasters are considered to be any adverse effects on the environment. They include environmental disaster "events" as well as additive effects over time, resulting in perceivable changes in ecosystem health. The environmental threshold variable determines the level at which an environmental disaster will occur. During the postpay system of regulation, environmental damage payments are deducted from firm assets. During the prepay system, they are deducted from the assurance bond (Fig. 1a, Assets Submodel).

The assurance bond is established with a one-time deposit from firm assets (Fig. 1d). This occurs when the regulation system switches to the prepayment system at some randomly selected time between time steps 20 and 40 during the simulation. The firm management simulation runs for a total of 60 time steps (simulated years). Once the bond is established, it accumulates interest, which increases the bond's value over time. Refunds to the firm are granted on a yearly basis when costs of environmental damages are less than the assessed estimate. A portion of the interest also accumulates in an environmental research fund.

2.2. The game

The model was made into an interactive game using STELLAStack® (High Performance Inc.), a two-way interface between STELLA® and Hypercard® software. Hypercard makes the simulation model "playable" as a game with only minimal training required for the player. It enables the novice to interact indirectly with the STELLA® model and, thus, not only make decisions while the simulation is unfolding, but also examine the consequence of those decisions. Production level and the amount of resources devoted to waste reduction are the only variables players can manipulate. The game begins with these variables set at a default level (see Appendix 1). Because the play screen is linked directly to the model through StellaStack, when players make changes in production level or waste reduction technology, these translate into parameter changes in the model. Changes can be made at any time during the running of the game. If the player does not choose to make any manipulations, these variables will be determined by the model.

The game begins by prompting the player to log in their name, occupation, address, gender, and age as well as some simple instructions on how to play the game and what the objectives are. Each time a player begins a new game, a random level of uncertainty is established. Model-generated data on assets, annual profits, total costs, cumulative environmental damage and the assurance bond are displayed for players on a yearly basis (Fig. 2). Besides the information on the play screen, participants can view their progress over time by examining the environmental graphs, economic graphs, bond graphs, and profit graphs (Fig. 3). When the charge system changes from postpay to prepay, the player is notified that the assurance bonding system is in effect and that it generates interest, a portion of which will be refunded to the firm.

2.3. Players

Volunteers for this study consisted of Environmental Protection Agency personnel, graduate students in a public policy course at the University of Maryland, students and faculty at the Chesapeake Biological Laboratory and, for an international perspective, faculty and students at the University of Stockholm in Sweden. Participants were given some preliminary instructions about using the computer and told that the object of the game was to maximize profits. Because of the realities of increased environmental awareness, moral obligations to society and the influence negative environmental press could have on sales, players were also told that they might want to think about minimizing environmental damage. They were also informed that the game was designed to study two types of pollution abatement strategies. All responses entered by the study subjects were recorded by the computer in an output file.

As previously mentioned, the game is designed to test player behavior under a prepayment (assurance bonding) versus a postpayment (command and control) system, with varying degrees of uncertainty. Our measure of player performance, an environmental cost efficiency index (ECEI), was calculated by dividing total cumulative profit by total cumulative waste. We did not use the standard index of efficiency used in economic experiments (the experimentally observed net social benefits divided by the maximum possible expected net social benefits) because we are arguing that the social cost of pollution is often uncertain or unknown. Because of this, we did not want to assign an arbitrary value to pollution.

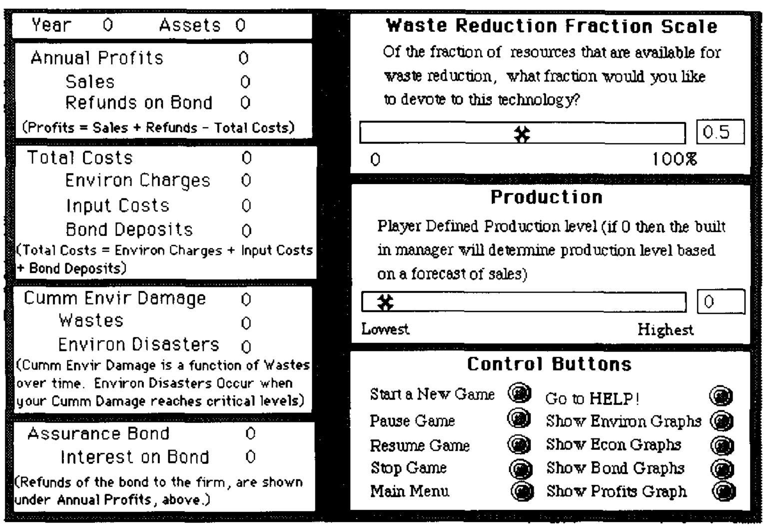
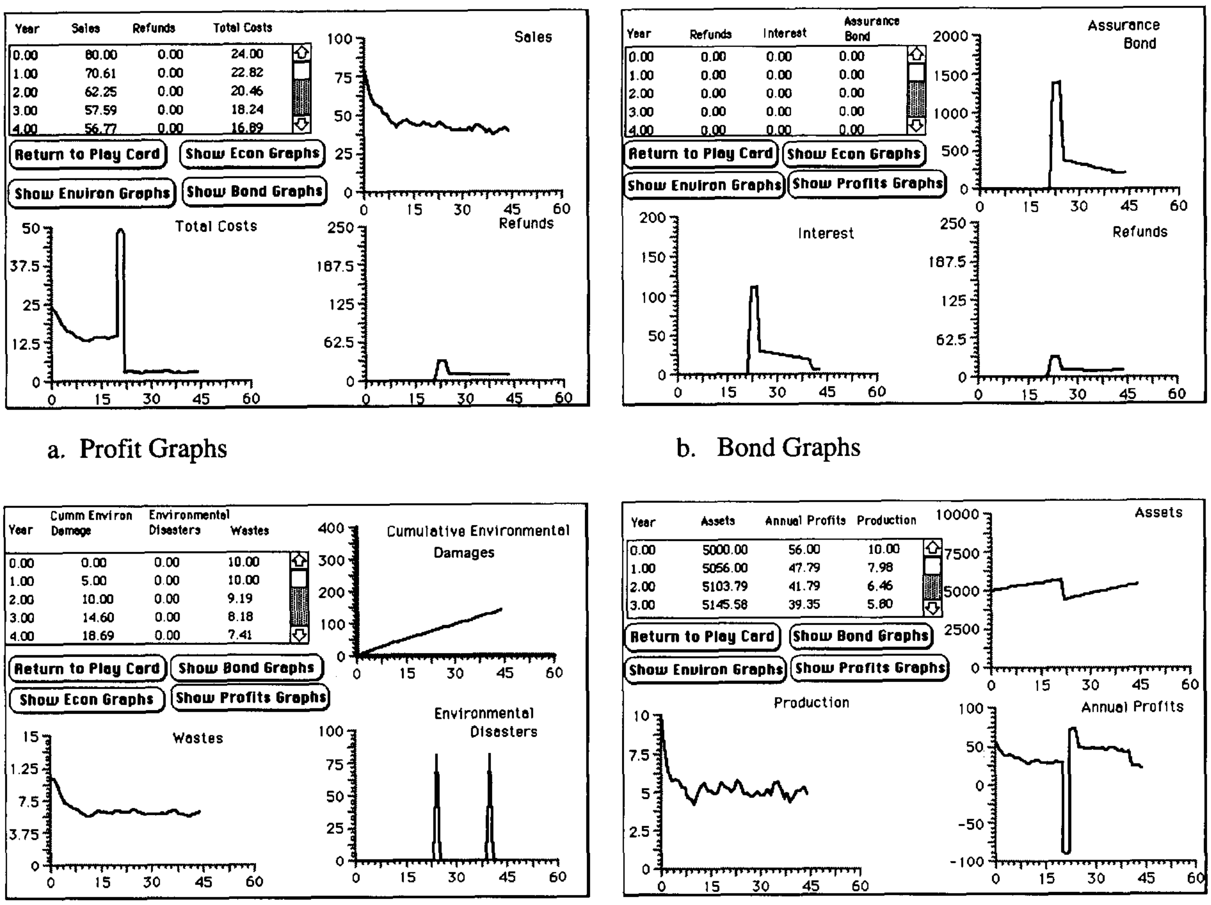


Fig. 2. The "play" screen where management decisions are made by players.

Instead, we decided to determine which system offered the greatest environmental efficiency. As the ECEI value increases, management decisions are considered more efficient since annual profits were being made with the least environmental impact. We hypothesized that players would have the incentive to manage "their firm" in a more environmentally efficient way under the prepay system and that this efficiency gain would be most pronounced when uncertainty was high. As a result, ECEI values under the prepay system will be greater than under the postpay system.

3. Results

Data were partitioned into two samples, values generated by the model during the postpay system and those generated during the assurance bonding system. Thirty-three games were run with no players. Without player manipulation, all variable values are determined by the model. The output files from these games constituted the control data. The efficiency index of the two charge systems was compared using a paired t-test. The relationship between ECEI and uncer-



a. Profit Graphs

b. Bond Graphs

c. Environmental Graphs

d. Econ Graphs

Fig. 3. Examples of progress over time as viewed by players of the game. Only one set of graphs can be viewed at a time. a. Profit Graphs include output over time of firm sales, refunds from the bond and total costs. b. Bond Graphs include output over time of total bond amount, interest earned on the bond and refunds to the firm of the bond. c. Environmental Graphs include output over time of cumulative environmental damages wastes produced by the firm and environmental disasters caused as a result of firm wastes. d. Econ Graphs include output over time of firm assets, production level and annual profits.

tainty was determined for both samples using linear regression. The resulting slopes were compared using the F-test (Sokal and Rohlf, 1981) to determine if under high uncertainty conditions players performed significantly better under the assurance bonding system than under the command and control system.

Player characteristics were analyzed with ECEI to better understand the role that these characteristics have on player performance. Two analyses were used to determine if player characteristics affect ECEI. Multiple regression models were constructed with eight variables (age, game number, time of change to the prepay system, charge system, gender, residence, occupation and uncertainty), five variables (age, game number, time of change to the prepay system, charge system, and uncertainty) and three variables (age, game number, and charge system). Unpaired t-tests were used to examine ECEI between places of residence (U.S. or Sweden) and occupations. Player occupation was divided into the following categories: economists, natural scientists, policy professionals, students, and engineers. Because the last two categories have small sample sizes, they were not included in all analyses (but were included in the 8-variable model). For all possible occupation pairs, variance homogeneity was tested using the F_{max} test (Sokal and Rohlf, 1981). Analyses were then performed using the unpaired t-test for unequal sample sizes and, where appropriate, unequal variances (Snedecor and Cochran, 1980). ECEI scores of males and females were also compared using the t-test for unequal sample size. Finally, regression models were constructed to examine the relationship between ECEI and various combinations of explanatory variables for both the prepay system and the postpay system (Table 1).

Thirty-six people played the game a total of 101 times for an average of 2.89 games per player. The average age of the study subjects was 35 (range 22–60). The model inherently performs better (i.e., with no player input) under the prepay system (mean ECEI = 9.706) than the postpay system (mean ECEI = 4.552), due to initial

Table 1
Multiple regression of the eight-, five-, and three-variable models. The independent variable in all cases was ECEI

Dependent variables	Coefficient	St. error	t-value	Probability
8-variable model [a]				
Game number	0.927	0.232	3.996	0.0001
Charge system	8.113	1.375	5.903	0.0001
Age	−0.227	0.090	2.532	0.0124
Change to prepay system	−5.312	2.372	2.239	0.0266
Uncertainty	107.278	47.181	2.274	0.0244
Occupation	0.1341	0.7227	0.186	0.8531
Residence	0.353	0.461	0.765	0.4453
Gender	−0.067	1.969	0.034	0.973
5-variable model [b]				
Game number	1.026	0.189	5.42	0.0001
Charge system	7.178	1.194	6.012	0.0001
Age	−0.226	0.064	3.516	0.0005
Change to prepay system	−3.902	2.068	1.887	0.0607
Uncertainty	78.314	41.048	1.908	0.0579
3-variable model [c]				
Game number	0.976	0.188	5.202	0.0001
Charge system	7.164	1.200	10.973	0.0001
Age	−0.226	0.063	3.612	0.0004 [a]

Intercept = 109.438, $R^2 = 0.359$, $F = 10.304$, $P = 0.0001$.
[b] Intercept = 82.788, $R^2 = 0.322$, $F = 18.159$, $P = 0.0001$.
[c] Intercept = 7.055, $R^2 = 0.309$, $F = 28.741$, $P = 0.0001$.

conditions and returns from interest. Because of this bias, the mean ECEI for control games was subtracted from experimental ECEI values to create adjusted scores which were used for subsequent analysis. The command and control system generated more than four times the amount of wastes per unit profit than the assurance bond system ($t_{0.05,199} = -5.14$, $P = 0.001$). There was no significant relationship between adjusted ECEI and uncertainty during the prepay system ($y = 3.95x + 7.38$, $F_{1,99} = 0.9422$, $P = 0.3341$) nor during the postpay system ($y = 0.7413x + 2.099$, $F_{1,98} = 0.1622$, $P = 0.688$). A comparison of the regression lines revealed the relationship between ECEI and uncertainty was not significantly different between the two charge systems ($F_{1,98} = 0.065$, $P > 0.05$).

The results of the regression models are shown in Table 1. There were highly significant relationships between adjusted ECEI values and game number, charge system, and age for all three models. The time of change to the prepay system and uncertainty were only significant in the 8-variable model while occupation, residence, and gender were not significant in any of the models. The results of the 5-variable regression model for predicted and actual ECEI values are plotted in Fig. 4. It is interesting to note that although there is a significant range of ECEI values for both charge systems, all of the highest ECEI values (> 20) were generated during the prepay system.

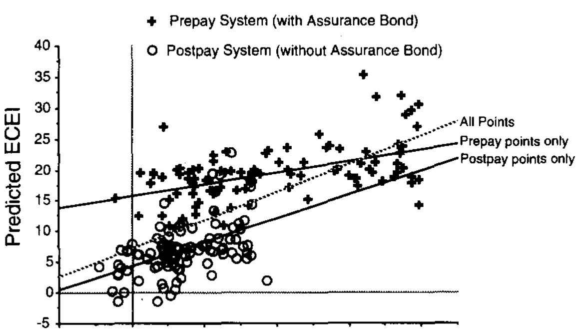


Fig. 4. Plot of ECEI for the prepay and postpay systems against the predicted values for ECEI from the 5-variable model. The overall r^2 for the model was 0.322.

Results of an unpaired t-test for unequal sample size showed that players from Sweden had nearly twice the adjusted ECEI values of players from the U.S. ($t_{0.05,199} = 2.356$, $P = 0.0195$). ECEI was significantly higher for natural scientists than for policy professionals ($t_{0.05,103} = 2.19$, $P = 0.031$) and was the only t-test between occupations that was significant. However, adjusted ECEI scores increased with game number, and when analyzing scores for first and second games only, no significant difference occurred ($t_{0.05,61} = 0.978$, $P = 0.332$). There were considerably more male players than females and, in general, males played more games. Adjusted ECEI mean values were significantly higher for males than for females ($t_{0.05,199} = -2.162$, $P = 0.0318$), but only when considering all games played. ECEI values from first games indicated no significant difference between males and females ($t_{0.05,70} = 1.268$, $P = 0.2088$). Likewise, there was no significant difference between males and females for second games ($t_{0.05,43} = 0.355$, $P = 0.725$).

4. Discussion

As expected, the assurance bonding pollution abatement system improved player performance when managing a simulated firm. We suspect this is due to the incentives that this system provides for the "managers." Charge system is by far the most important explanatory variable in all of the models. When the change to the prepay system occurs, players are informed by a pause in the simulation and an information screen. This allows players to evaluate past performance and rethink strategy. However, contrary to expectations, the level of uncertainty does not significantly affect player behavior except in the 8-variable model. The reason for this may be that players were not given direct information about uncertainty levels. They reacted to uncertainty by assessing model output. If players were directly informed about uncertainty values (e.g., by showing a message at the beginning of the game that indicates "your chances of getting caught and/or charged for a pollution violation in the postpay system are $x\%$"), they would have the opportunity to develop strategies and perhaps would have engaged in more risky behavior if the probability of getting caught and charged was low. In future experiments, we plan to communicate more information about uncertainty levels during the game.

The strongly significant relationship between ECEI and game number suggests that players learn as they played more games. The significant difference between males and females appears to be a direct result of number of games played. Only one female played more than three games. Although computer literacy and familiarity with the Macintosh system were not surveyed in the game, those unfamiliar with computers may have initially been intimidated by the manipulations required to play the game. The fact that age is a significant explanatory variable and exhibits a negative coefficient may be a result of "computer phobia." It is also interesting to note that, while players from Sweden have significantly higher ECEI values than players from the U.S., when taking other variables into account (i.e., in the 8-variable model) country is not a significant explanatory variable. In future experiments we plan to investigate further the effects of cultural background on performance.

The fact that "time of change to the prepay system" is significant in the 8-variable model and almost significant in the 5-variable model suggests that this variable is potentially important and also requires further investigation. In future experiments we plan to allow more variation in the "time to change" variable to avoid clustering of values in the middle of the game. Increasing the sample size of players with different occupations also seems like a valuable exercise. The amount of knowledge or information that a player had prior to beginning any given game seemed to make a difference in player performance (players "learned" as they played the game). It would be interesting in future experiments to provide different instruction sets to different players to determine how information affects results. In general, we think this preliminary application of the simulation model/game/experiment approach was quite successful and substantiated our main hypothesis that the prepay system provides players with the incentive to improve their economic and environmental performance in the game when compared with the postpay system. This experimental evidence is bolstered by recent theoretical results (Farber, 1991). The experimental approach to understanding economic behavior has tremendous potential (cf. Smith and Williams, 1992), both as an analytical tool and as a teaching device. The results of the experiment described in this paper are preliminary, but encouraging. While not conclusive, they indicate that the prepay (assurance bonding) system may be an effective incentive to improve a firm's environmental behavior. However, as in any healthy science, we fully realize that we have raised more questions than we have answered and have set the stage for additional experimental studies in the future.

Acknowledgments

Partial Funding for this project was provided by the U.S. EPA, contract #CR-815393-01-0, S. Farber and R. Costanza, Principal Investigators, titled: "A Flexible Environmental Cost Charging and Assurance Bonding System for Improved Environmental Management." The authors would like to thank game participants as well as Paul Jivoff, Lisa Wainger, Enrique Reyes, Dan Mussatti, Clem Tisdell, and an anonymous reviewer for helpful comments on earlier drafts. Of course, any remaining errors are our own.

Appendix

Appendix 1
Model symbol definitions

Symbol	Definition
State variables	
Acc Env Fnd	Accumulated Environmental Fund = Acc Env Fnd + dt *(Env Res Fnd) INIT(Acc Env Fnd) = 0
Assets	Assets = Assets + dt *(Monetary inputs − Total Costs) INIT(Assets) = 5000
Assur Bond	Assurance Bond = Assur Bond + dt *(Deposits − Damage Deduction − Refunds + Interest − Env Res Fnd) INIT(Assur Bond) = 0
Cum Dischar	Cumulative Discharge = Cumm Dischar + dt * (Discharged − Discharged Liabil) INIT(Cumm Dischar) = 0
Cum Env Damage	Cumulative Environmental Damage = Cumm Env Damage + dt *(damages) INIT(Cumm Env Damage) = 0
Inventory	Inventory = Inventory + dt *(−Shipments + Production) INIT(Inventory) = 100
Wastes	Wastes = Wastes + dt *(Waste Production − Discharged) INIT(Wastes) = 10
Inputs	
Damages	Damages = Discharged
Deposits	Deposits into Bond = IF Del Charge > 0.1 THEN Worst Case Estimate ELSE 0
Discharged	Wastes Discharged into the Environment = Wastes *0.5
Env Res Fnd	Environmental Research Fund = Interest *(0.8 − Int frac to firm)
Interest	Interest = Assur Bond *0.08
Monetary inputs	Monetary Inputs into Firm Assets = Sales + Refunds
Production	Level of Production = IF Usr Prod = 0 THEN Forcast Shipmts ELSE Usr Prod
Waste Production	Amount of Waste Production = 1 + Production *((1 − WasteReducTech) *Waste Fraction)
Outputs	
Damage Deduction	Damage Deduction = IF Charge System = 1 THEN (4 *Discharged *(1 − Uncert)) + 14*n*v Disaster *(1 − Uncert) ELSE 0
Discharged	Wastes Discharged into the Environment = Wastes *0.5
Discharged Liabil	Discharged Liability = 0.6 *Env Disaster
Env Res Fnd	Environmental Research Fund = Interest *(0.8 − Int frac to firm)
Refunds	Refunds to the Firm = IF Charge System = 1 THEN (Max Discharges − Discharged) + (Int frac to firm *Interest) ELSE 0
Shipments	Shipments of Inventory = SMTH1(Product Demand,5,10)
Total Costs	Total Costs to the Firm = Input costs + Deposits + PostPaid Damages
External variables	
Annual Profits	Annual Profits = Monetary inputs − Total Costs
Charge System	Charge System = IF (TIME < T of Change to Pre) THEN Postpay ELSE Prepay
Del Charge	Delay Charge = Charge System − DELAY(Charge System,1,INIT(Charge System))
Diaster Threshold	Disaster Threshold = 70
Env Disaster	Environmental Disaster = IF (Cumm Dischar *RANDOM) > disaster threshold THEN Cumm Dischar ELSE 0
Forcast Shipmts	Future Shipments = FORCST(Shipments,5,5)
Input costs	Input costs = 1 *(Unit Inp Cost + Unit Waste Red Cost) *(Production)
Int frac to firm	Fraction of Interest Returned to the Firm = 0.25
Market price	Market Price = 8
Max Discharges	Maximum Discharge in any given year = 7
PostPaid Damages	Environmental Damages Occurring During the Postpay System = IF Charge System = 0 THEN (4 *Discharged *(1 − Uncert)) + 14 *Env Disaster *(1 − Uncert) ELSE 0

Postpay	An Indicator Variable of the Postpay system (= 0)
Prepay	An Indicator Variable of the Prepay system (= 1)
Product Demand	Level of Product Demand = 3 + (4 *RANDOM)
Rand	Generates numbers between 0 and 1, randomly
Sales	Sales = Market Price *Shipments
Total Withdraw	Total Withdraws from the Bond = Refunds + Damage Deduction
T of Change to Pre	Time in the Game when the Charge System Changes to Prepay = INT(20 + 20 *INIT(Rand))
Uncert	Uncertainty = INTI(random) or a number is selected randomly between 0 and 1
Unit Inp Cost	Unit Cost of Inputs = graph(Waste Fraction). Graphical Points Include (0.0,0.910),(0.100,0.745),(0.200,0.650),(0.300,0.550),(0.400,0.485), (0.500,0.440),(0.600,0.395),(0.700,0.355),(0.800,0.335), (0.900,0.315),(1.00,0.300)
Unit Waste Red Cost	Unit Cost of Waste Reduction = graph(WasteReducTech). Graph Points Include (0.0,0.0200),(0.100,0.0500),(0.200,0.0800),(0.300,0.120), (0.400,0.180),(0.500,0.250),(0.600,0.310),(0.700,0.380), (0.800,0.495),(0.900,0.665),(1.00,0.950)
Usr Prod	User Production = This variable allows players of the game to over ride the level of firm production set by the model
WasteReducTech	Waste Reduction Technology is initially set at 0.5, but can be changed at any time by the player of the game
Waste Fraction	The Percentage of Inputs that end up as Waste = 0.5
Worst Case Estimate	Estimate of the Worst Case Damages = Max Discharges *200

References

Ackerman, B. and Stewart, R., 1985. Reforming environmental law: the democratic case for market incentives. Columbia J. Environ. Law, 13: 171–199.

Adar, Z. and Griffin, J., 1976. Uncertainty and the choice of pollution control instruments. J. Environ. Econ. Manage., 3: 178–188.

Atkinson, S. and Lewis, D., 1974. A cost-effectiveness analysis of alternative air quality control strategies. J. Environ. Econ. Manage., 1: 237–250.

Atkinson, S. and Lewis, D., 1976. Determination and implementation of optimal air quality standards. J. Environ. Econ. Manage., 3: 363–380.

Atkinson, S. and Tietenberg, T., 1982. The empirical properties of two classes of designs for transferable discharge permit markets. J. Environ. Econ. Manage., 9: 101–121.

Averch, H. and Johnson, L., 1962. Behavior of the firm under regulatory constraint. Am. Econ. Rev., 52: 1053–1069.

Axelrod, R., 1984. The Evolution of Cooperation. Basic Books, New York, NY.

Baron, D. and Taggart, R., Jr., 1977. A model of regulation under uncertainty and a test of regulatory bias. Bell J. Econ., 8: 151–167.

Baumol, W. and Oates, W., 1988. The Theory of Environmental Policy. Cambridge University Press, New York, NY, 299 pp.

Beavis, B. and Walker, M., 1979. Interactive pollutants and joint abatement costs: achieving water quality standards with effluent charges. J. Environ. Econ. Manage., 6: 275–286.

Bohm, P., 1981. Deposit-Refund Systems: Theory and Applications to Environmental, Conservation, and Consumer Policy. Johns Hopkins University Press, Baltimore, MD.

Boulding, K., 1966. The economics of the coming spaceship earth. In: H. Daly and K. Townsend (Editors), Valuing the Earth. MIT Press, Cambridge, MA, pp. 297–309 (1993).

Brooks, M. and Heijdra, B., 1987. Rent-seeking and pollution taxation: an extension. South. Econ. J., 54: 335–342.

Burrows, P., 1979. Pigovian taxes, polluter subsidies, regulation, and the size of a polluting industry. Can. J. Econ., 12: 494–501.

Carson, R., 1962. Silent Spring. Fawcett Publications Inc., Greenwich.

Common, M., 1977. A note on the use of taxes to control pollution. Scand. J. Econ., 79: 346–349.

Conrad, K., 1987. An incentive scheme for optimal pricing and environmental protection. J. Inst. Theor. Econ., 143: 402–421.

Costanza, R., 1987a. Social traps and environmental policy. BioScience, 37: 407–412.

Costanza, R., 1987b. Simulation modeling on the Macintosh using STELLA. BioScience, 37: 129–132.

Costanza, R. and Cornwell, L., 1992. The 4P approach to dealing with scientific uncertainty. Environment, 34(9): 12–20.

Costanza, R. and Perrings, C., 1990. A flexible assurance bonding system for improved environmental management. Ecol. Econ., 2: 57–75.

Costanza, R. and Shrum, W., 1988. The effects of taxation on moderating the conflict escalation process: an experiment using the dollar auction game. Soc. Sci. Q., 69: 416–432.

Cross, J. and Guyer, M., 1980. Social Traps. University of Michigan Press, Ann Arbor, MI.
Edney, J. and Harper, C., 1978. The effects of information in a resource management problem: A social trap analogy. Human Ecol., 6: 387–395.
Endres, A., 1983. Do effluent charges (always) reduce environmental damage? Oxford Econ. Papers, 35: 254–261.
Farber, S., 1991. Regulatory schemes and self-protective environmental risk control: a comparison of insurance, liability and deposit/refund system. Ecol. Econ., 3: 231–245.
Fishelson, G., 1976. Emission control policies under uncertainty. J. Environ. Econ. Manage., 3: 189–197.
Freeman, A.M., III., 1990. Economics, incentives and environmental regulation. In: N. Vig and M. Kraft (Editors), Environmental Policy in the 1990's. Congressional Quarterly Inc., Washington, DC, pp. 145–166.
Haas, C., 1985. Incentive options for hazardous waste management. J. Environ. Syst., 14: 373–393.
Hahn, R. and Noll, R., 1983. Barriers to implementing tradable air pollution permits: problems of regulatory interactions. Yale J. Regulat., 1: 63–91.
Hahn, R. and Hester, G., 1989. Marketable permits: lessons for theory and practice. Ecol. Law Q., 16: 361–406.
Hamilton, J., Sheshinski, E. and Slutsky, S., 1989. Production externalities and long-run equilibria: bargaining and Pigovian taxation. Econ. Inquiry, 27: 453–471.
Hardin, G., 1968. The tragedy of the commons. Science, 162: 1243–1248.
Harford, J., 1987. Self-reporting of pollution and the firm's behavior under imperfectly enforceable regulation. J. Environ. Econ. Manage., 14: 293–303.
Katzman, M., 1987. Pollution liability insurance and catastrophic environmental risk. J. Risk Insur., 34: 75–100.
Koenig, E., 1984. Uncertainty and pollution: the role of indirect taxation. J. Publ. Econ., 24: 111–122.
Kohn, R., 1977. Emission standards and price distortion. J. Environ. Econ. Manage., 4: 200–208.
Krupnick, A., 1983. Costs of alternative policies for the control of NO_2 in the Baltimore region. Resources for the Future, Washington, DC.
Krupnick, A., Oates, W. and Van De Verg, E., 1983. On marketable air pollution permits: the case for a system of pollution offsets. In: E. Joeres and M. David (Editors), Buying a Better Environment: Cost Effective Regulation through Permit Trading. University of Wisconsin Press, Madison, WI.
Lee, D., 1984. The economics of enforcing pollution taxation. J. Environ. Econ. Manage., 11: 147–160.
Magat, W., 1978. Pollution control and technological advance: A dynamic model of the firm. J. Environ. Econ. Manage., 5: 1–25.
Marquand, J., 1981. An economist's view of pollution charges as regulatory instruments. In: J. Butlin (Editor), Economics of Environmental and Natural Resources Policy. Westview Press, Boulder, CO, pp. 153–160.
McHugh, R., 1985. The potential for private cost-increasing technological innovation under a tax-based, economic incentive pollution control policy. Land Econ., 61: 58–64.
Mendelsohn, R., 1984. Endogenous technical change and environmental regulation. J. Environ. Econ. Manage., 11: 202–207.
Mill, E.S., 1972. Urban Economics. Scott Forseman, Glenville, IL.
Milliman, S. and Prince, R., 1989. Firm incentives to promote technological change in pollution control. J. Environ. Econ. Manage., 17: 247–265.
Peles, Y. and Stein, J., 1976. The effect of rate of return regulation is highly sensitive to the nature of uncertainty. Am. Econ. Rev., 66: 278–289.
Perrings, C., 1987. Economy and Environment: a Theoretical Essay on the Interdependence of Economic and Environmental Systems. Cambridge University Press, New York, NY, 179 pp.
Perrings, C., 1989. Environmental bonds and the incentive to research in activities involving uncertain future effects. Ecol. Econ., 1: 95–110.
Pethig, R. and Fiedler, K., 1989. Effluent charges on municipal wastewater treatment facilities: in search of their theoretical rationale. J. Econ., 49: 71–94.
Platt, J., 1973. Social Traps. Am. Psychol., 28: 642–651.
Plourde, C. and Yeung, D., 1989. A model of industrial pollution in a stochastic environment. J. Environ. Econ. Manage., 16: 97–105.
Roberts, M. and Spence, M., 1976. Effluent charges and licenses under uncertainty. J. Publ. Econ., 5: 193–208.
Seskin, E., Anderson, R., Jr. and Reid, R., 1983. An empirical analysis of economic strategies for controlling air pollution. J. Environ. Econ. Manage., 10: 112–124.
Shaw, B., Winslett, B. and Cross, F., 1987. The global environment: a proposal to eliminate marine oil pollution. Nat. Resourc. J., 27: 157–185.
Smith, V. and Williams, A., 1992. Experimental market economics. Sci. Am., 267: 116–121.
Snedecor, G. and Cochran, W., 1980. Statistical Methods. The Iowa State University Press, Ames, IA, 507 pp.
Sokal, R. and Rohlf, F., 1981. Biometry. W.H. Freeman and Company, New York, NY, 859 pp.
Solow, R., 1971. The economist's solution to pollution control. Science, 173: 498–503.
Stollery, K., 1985. Environmental controls in extractive industries. Land Econ., 61: 136–144.
Tietenberg, T., 1973. Specific taxes and the control of pollution: a general equilibrium analysis. Q.J. Econ., 87: 503–522.
Tietenberg, T., 1985. Emissions Trading: an Exercise in Reforming Pollution Policy. John Hopkins University Press for: Resources for the Future, Baltimore, MD.
Webber, B. and Webber, D., 1985. Promoting economic incentives for environmental protection in the surface mining control and reclamation act of 1977: an analysis of the design and implementation of reclamation performance bonds. Nat. Resourc. J., 25: 390–414.
Weitzman, M., 1974. Prices vs. quantities. Rev. Econ. Stud., 68: 683–691.
White, L., 1976. Effluent charges as a faster means of achieving pollution abatement. Publ. Policy, 24: 111–125.