No. 330 July 1991

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by Jay S. Coggins
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*Assistant Professor, Department of Agricultural Economics, University of Wisconsin-Madison and Assistant Professor, Department of Agricultural Economics and Economics, Montana State University, respectively. We thank Joe Atwood, Ron Johnson, Ken Rose and Rick Stroup for helpful discussions. Coggins acknowledges the research support of the National Regulatory Research Institute, Columbus, Ohio. This research has not been subjected to the NRRI's formal review proceedings.

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ENVIRONMENTAL CONTROL AND EMISSION ALLOWANCE TRADING: THE CASE OF REGULATED UTILITIES

1. Introduction

For over twenty years, economists have advocated the use of market-based tradable pollution permits as an efficient means of attaining many environmental policy objectives (Dales 1968; Montgomery 1972). In the absence of complicating market imperfections, no alternative regulatory scheme can achieve a given environmental goal more cheaply than a market-based emission permit scheme.[1] Though Malueg (1990) has addressed the effects of imperfections in the output market of permit trading firms, little attention has been given to the effects of economic regulation. In particular, a question of considerable importance is whether the strong efficiency results attributed to permit trading hold when participating firms are utilities that must comply with rate-of-return regulation. This paper examines the economic implications of two environmental regulatory alternatives—(*i.*) command and control policies and (*ii.*) marketable permit schemes—when the polluting industry consists of rate-of-return regulated firms such as electric utilities that face binding environmental pollution emission constraints. The paper thus attempts to integrate the theory of marketable pollution permits with the theory of regulated industries in order to examine the economic consequences of the interaction between environmental and regulatory policy.[2]

The issues we examine are apposite. The US Clean Air Act Amendments of 1990, signed into law by President Bush on November 15, 1990, have replaced command and control regulations governing sulfur dioxide (SO_2) emissions from electric power plants with a market-based permit scheme intended to lower emissions of SO_2. Title IV of the Amendments requires that SO_2 emissions be reduced by 10 million tons below 1980 levels (to a nationwide total emissions level of 8.95 million

[1] Evidently, A.C. Pigou (1932) was the first to argue that a market-based scheme for pollution control would exhibit desirable efficiency properties. Dales (1968) later refined and extended that argument, and Montgomery (1972) provided the first rigorous mathematical treatment. More recently, attention has been directed increasingly to the performance of permit systems in the presence of imperfections of one sort or another. See, *inter alia*, Hahn (1984); Lyon (1986); Malueg (1990); and Tripp and Dudek (1986).

[2] For a recent survey of the literature on utility regulation, see Joskow and Rose (1989). Laplante (1990) considers the effect of subsidizing pollution control equipment on firm's output choices, using a model of strategic behavior in an oligopolistic industry, but he does not examine the effect of market-based environmental control. We know of only one other study, by Bohi and Burtraw (1991), that considers formally the interaction between utility and market-based environmental regulation.

tons) by the year 2000. Nearly all electric power utilities will be affected by the new bill, and most will have to reduce their emissions levels in order for the industry to comply with this requirement.

The 1990 Amendments provide emitting sources with considerable latitude in choosing compliance strategies. Each electric utility will receive an allocation of emission allowances or permits (where, in the language of the 1990 Amendments, an *allowance* is the right to emit one ton of sulfur dioxide on or after the year that it is issued). Utilities may then choose to comply with Title IV requirements by (*i.*) reducing emissions to match the initial allowance allocation; (*ii.*) reducing emissions below that level and generating excess allowances for sale to other utilities; or (*iii.*) emitting more than the initial allotment and purchasing allowances from other utilities.[3]

This paper demonstrates that the firm's actual emissions compliance strategy is affected by the policies of public utility regulatory agencies. Moreover, we show that the effects of regulatory policies on the price and traded quantity of emission allowances are complex. In section 2 we begin by examining the effects of regulatory policy on the compliance strategy selected by a utility facing command and control pollution abatement regulations of the type that existed prior to the 1990 Amendments. Section 3 extends the model of the firm to include marketable emission allowances and examines some qualitative implications of changes in public utility regulatory agency policies for the quantity traded and prices of emission allowance prices. Conclusions are presented in Section 4.

2. Command and Control Environmental Regulation

A command and control (CAC) environmental policy prescribes the maximum level of pollution emissions permitted at emitting firms' production facilities. Often, specific abatement technologies are also mandated. This section presents model of a regulated firm that faces two constraints. One constraint limits the rate of return on capital investments. The other limits emissions of some pollutant of interest. The introduction of an emissions constraint into the model of a rate of return regulated (ROR) firm results in some surprising changes in the firm's behavior, and provides interesting insights about the interaction between the two distinct regulatory programs. Thus we extend the Averch and Johnson (A-J) model of a ROR regulated monopoly to include an environmental constraint.[4] In the model presented in this section, the environmental constraint

[3] Emissions may be reduced in any one of a number of ways, including simply reducing output, installing capital-intensive scrubbers, repowering to upgrade boiler efficiency, switching to low-sulfur coal, and so on.

[4] Averch and Johnson's primary result—that regulated utilities have an incentive to overcapitalize—has become

appears simply as an absolute upper bound on emissions, e. The environmental regulator chooses an upper bound E_0 for emissions, and it is assumed throughout that the required control of emissions is perfect—firms do not cheat on their environmental obligations.

The firm is assumed to be a profit-maximizing monopolist that faces two constraints: the ROR restriction on its invested capital and the CAC emissions constraint. It also owns two technologies. The firm's *production technology* is characterized by a twice differentiable production function $q = f(x, k_1)$, where x is a variable input (say, labor) and k_1 is productive capital. It is assumed that f is continuously differentiable and strictly increasing in both inputs. The firm's *abatement technology* links the level of output q and abatement capital k_2 to pollution emissions through an emission function $e = h(q, k_2)$.[5] Emissions are assumed to increase with output (that is, $\partial h/\partial q > 0$) and decrease with k_2 (that is, $\partial h/\partial k_2 < 0$). In addition, we assume that as output increases, the effectiveness of a unit of abatement capital decreases (that is, $\partial^2 h/\partial q \partial k_2 < 0$). The pollution regulation simply requires that the firm's emissions be lower that some maximum emissions level E_0; that is, $h(q, k_2) \leq E_0$. This means that the firm can use one or both of two abatement strategies to comply with the emission regulation; it can reduce output or expand its use of pollution control equipment, or it can do both.

The firm faces a strictly downward-sloping inverse demand function $p(q)$ that depends only upon its level of production q. Both kinds of capital are assumed to be available in any amount at the price $r > 0$, and x may be purchased at w per unit. Without loss of generality, we assume that the acquisition cost of capital is unity, and we also assume that there is no depreciation. The firm's profits are given by $\pi = p(q)q - wx - r(k_1 + k_2)$. In the absence of ROR regulation, the monopoly firm would simply solve this concave objective function for a maximum in x, k_1, and k_2. The firm's profits, however, are constrained by the ROR constraint. The PUC must make two decisions regarding this constraint. The first is the actual rate that the firm is allowed to earn on

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known as the "A-J effect". Joskow (1974) argues that utilities do not have an incentive to overcapitalize during times of inflation and when regulatory review is uncertain. More recently, economists have explored alternatives to rate of return regulation (Braeutigam and Panzar 1989; and Hillman and Braeutigam 1989). Baron (1989) explains how "incentive regulation" has been and might be implemented. He also provides a model in which the firm and the regulator satisfy an incentive compatibility requirement and in which an equilibrium outcome coincides with the Averch Johnson overcapitalization result.

[5] It is perhaps most natural to think of k_2 as investment in flue-gas desulfurization equipment, or scrubbers, and this is the interpretation that we have in mind. We implicitly assume that scrubber size is a continuous variable. There are other capital costs that the firm may incur that would serve to reduce emissions, including the installation of a new boiler that is capable of burning coal more cleanly.

its capital. Let $s > r$ denote the allowed rate of return, so that the difference $s - r$ represents the extra-normal profit the firm is allowed to earn on its capital stock or *ratebase*.[6]

The second decision for the PUC concerns the make-up of the ratebase. In the A-J model, this ratebase is simply comprised of k_1, the productive capital stock. Abatement capital could also be included in the ratebase, but it is not at all clear whether such a policy is optimal. Here, we assume that all productive capital is incorporated in the ratebase but that some fraction $\varphi \in [0, 1]$ of abatement capital will be included in the ratebase.[7] The term φ may be viewed either as a constant determined by the regulator or as a risk neutral firm's estimate of the probability that any given dollar of abatement expenditure will be included in the ratebase. Thus, by changing φ, the PUC alters its regulatory strategy and the firm's decision problem.

Two mathematical features of the firm's problem will be useful in what follows. First, by the inverse function theorem, the derivative restrictions on $h(q, k_2)$ guarantee that for a given E_0 the level of abatement capital k_2 can be expressed as a function of q. Let this function be denoted $k_2 = g(q; E_0)$,[8] where $g'(q) = dg/dq > 0$. Second, the firm is not allowed to earn any extranormal profits on its labor costs. This means that it will always choose a cost-minimizing level of x for a given (k_1, q) pair. Therefore, the firm's decision problem is decomposed into two parts.[9] In the first part the firm chooses the cost-minimizing value of x given q and k_1. The cost of purchasing x is given by the variable cost function $C(w, q, k_1)$, defined as

$$C(w, q, k_1) = \min_{x \geq 0} \quad \{wx \mid q \leq f(x, k_1)\}.$$

In the second part, given $C(w, q, k_1)$, the firm selects q and k_1 to maximize profits subject to its ROR constraint. That there are only two decision variables follows from the fact that q uniquely determines k_2. The firm's decision problem may be written as

$$\text{(1)} \qquad \begin{aligned} \max_{q, k_1} \pi &= p(q)q - C(w, q, k_1) - r(k_1 + g(q)) \\ \text{s.t.} \quad \pi &\leq (s - r)(k_1 + \varphi g(q)). \end{aligned}$$

[6] If $s = r$, the solution to the firm's problem is indeterminate; in this model a utility that faces a ROR constraint with $s < r$ will simply exit the industry.

[7] In fact, some productive capital may be excluded from the ratebase (for example, investments in nuclear power plants) but, for ease of exposition we ignore this complication.

[8] To reduce notational clutter we will often suppress the reference to E_0 and simply write this function as $k_2 = g(q)$.

[9] This approach follows Diewert (1981), upon whose development of the A-J model we draw heavily.

The lagrangian function for this problem is given by

$$\mathcal{L}(q, k_1; \lambda) = p(q)q - C(w, q, k_1) - r(k_1 + g(q; E_0)) +$$
$$\lambda\big((s - r)(k_1 + \varphi g(q; E_0)) - p(q)q + C(w, q, k_1) + r(k_1 + g(q; E_0))\big),$$

where $\lambda \geq 0$. The first order necessary conditions for a solution to (1) are given by

$$(p + qp'(q) - \partial C/\partial q - rg'(q))(1 - \lambda) + \lambda(s - r)\varphi g'(q) = 0 \tag{2a}$$

$$\partial C/\partial k_1 + r - \lambda((s - r) + \partial C/\partial k_1 + r) = 0 \tag{2b}$$

$$p(q)q - C(w, q, k_1) - r(k_1 + g(q)) - (s - r)(k_1 + \varphi g(q)) = 0. \tag{2c}$$

From (2b), using the assumption $s > r$, it follows that $\lambda > 0$. What's more, equation (2b) also yields

$$\lambda = \frac{\partial C/\partial k_1 + r}{\partial C/\partial k_1 + s} < 1. \tag{2d}$$

These arguments establish that $\lambda \in (0, 1)$, an important fact that will be used below.

It is now possible to examine the firm's response to both environmental and economic regulatory oversight. The A-J model predicts that a ROR regulated firm will produce inefficiently, using more capital than it would if it minimized costs for a given level of output. We first show the surprising way that the need for k_2 and pollution abatement affect this outcome. In short, with CAC environmental regulation the overcapitalization persists, but it is mitigated by the fact that the firm can count both k_1 and k_2 as part of its ratebase. That is, the utility still has an incentive to inflate the ratebase, but it may now do so using k_2 as well as k_1, thus reducing its incentive to move off the efficient locus of input combinations.

In addition to the efficiency question, we also consider the effect that changes in φ have upon the firm's output and pricing decisions. An increase in φ, the proportion of abatement capital allowed in the ratebase, represents a more liberal treatment of abatement capital and creates the potential for higher profits on the part of the utility. At first blush it seems natural to believe that as φ increases, both the use of abatement capital and monopoly profits will increase. However, appearances can be deceptive. Note that the ROR constraint, if binding, holds profits below their pure monopoly value. Usually, profits will increase from the regulated situation only if the firm's output level is reduced. As Baumol and Klevorick (1970) have shown, only in exceptional cases will the firm produce less with ROR regulation than it would have produced without regulatory constraint.[10] A downward-sloping demand implies that the quantity produced by the firm determines consumers' welfare. Aggregate consumer surplus is everywhere increasing in q. We show that as φ increases q decreases, which therefore leaves consumers worse off; that is, consumer surplus is decreasing in φ.

We first consider the question of whether the firm uses a cost-minimizing input mix, and how this decision turns on the regulator's choice of φ. A brief look at the way this question is answered in the A-J model will help to motivate the result presented below. Let the set of all (k_1, x) pairs that set profits equal to the profit constraint be denoted $S = \{(k_1, x) \in R^2_+ \mid p(q)q - wx - rk_1 = (s-r)k_1\}$. It is easy to show, following Baumol and Klevorick (1970) that the firm will choose that point in S at which k_1 is a maximum. Level curves of the constraint set, along which $\pi = (s-r)k_1$ for a fixed level of π, consist of vertical lines in (k_1, x)-space. Thus the π-maximizing input mix in the A-J case is the right-most point of S, where a vertical line just touches the constraint set (see Figure 1.)

If at least a part of k_2 is placed in the ratebase, however, the utility is able to use this abatement capital to increase its profits. The fact that k_2, at least in part, can now be used in place of k_1 for purposes of profitably increasing the ratebase, eases the pressure to over-use productive capital, and the firm moves *closer* to an efficient production plan. Level curves of the new constraint set, given by $\pi = (s-r)(k_1 + \varphi g(q; E_0))$, are now of finite slope unless $\varphi = 0$. These results are summarized in the following proposition. (Our proofs appear in the appendix.)

PROPOSITION 1. *Suppose that $\varphi \in [0,1]$, $s > r$, and E_0 are given, and that f and $p(q)$ are well-behaved functions satisfying the smoothness and derivative properties specified above. Suppose further that $g(q; E_0)$ and $C(w, q, k_1)$ are as defined above, and that the rate of return and emission constraints are binding. Then as φ increases, the firm will move toward a cost-minimizing (k_1, x) pair. Formally, the profit-maximizing firm will choose a production plan satisfying*

i. If $\varphi = 0$, then the firm will select the Averch-Johnson input combination, maximizing its use of k_1 subject to the constraint;

ii. If $\varphi \in (0,1]$, then the firm will select an input combination that is between the A-J choice and the cost-minimizing choice, in the sense that k_1 gets smaller as φ increases.

[10] The A-J regulated firm will produce less output under regulatory constraint than it would without regulation so long as x and k_1 are complements in production (Baumol and Klevorick 1970, p. 178).

The economic interpretation of this result is as follows. If $\varphi = 0$, the firm will select the input combination that an A-J firm would choose, in which overcapitalization is most extreme. As φ increases the firm will move away from this extreme point, and toward an efficient (k_1, x) pair (one that minimizes production costs). However, the proof that appears in the appendix also shows that the firm will never choose a cost-minimizing plan. Therefore, while the ability to place pollution abatement capital in the ratebase removes some of the incentive to overinvest in k_1, that incentive never disappears completely. This result has an unequivocal implication. If the PUC's objective is to encourage efficient production, the ROR regulated firm that faces a CAC environmental constraint should be allowed to count its scrubber purchases in the ratebase.

Though efficiency in production is encouraged by liberal regulatory treatment of k_2, concerns for the welfare of consumers of electricity dictate the opposite choice. That is, in the presence of the two regulatory constraints, consumer surplus is *reduced* whenever φ is *increased*. We state this result, whose heuristic proof appears in the appendix, as follows.

PROPOSITION 2. *Under the conditions specified in Proposition 1 above, the firm's level of output q is decreasing in φ.*

The consequences of increasing φ can be determined as follows. Assume an initial equilibrium associated with an initial value of φ, say φ^0. Let k_1^0 and k_2^0 denote the optimal levels of capital at the initial equilibrium. Now suppose φ increases to $\varphi^1 > \varphi^0$. At the initial optimal values for k_1 and k_2, a higher level of profits is now permitted; that is, the profit constraint is no longer binding. Thus the firm is free to reorganize its production and abatement strategies to exploit this opportunity. However, profits are a decreasing function of output. Thus the only way to increase profits is to reduce q.

The reduction in q also causes the output price to increase and thus an increase in φ leads to a reduction in consumer surplus. From the perspective of the consumer, in fact, $\varphi = 0$ is optimal; that is, when the PUC allows the utility a rate of return in excess of the market rate of return then consumer welfare will be maximized if no abatement capital is included in the ratebase. On the other hand, as long as the utility faces a binding rate of return constraint it has an incentive to lobby for $\varphi = 1$; that is, the firm's interests are best served if all pollution abatement equipment is included in the ratebase. In effect, the firm is then able more closely to approach its unconstrained profit maximizing policy.

It is interesting to note in this connection that in 49 of the 50 states, state public utility commissions do include all abatement capital in the ratebase.[11] This clearly benefits the utility at the expense of the consumer, reduces economic surplus in the electric power market and suggests, in relation to the use of environmental equipment, regulatory capture by the utilities.

It is also possible to deduce the effect of regulatory treatment of abatement capital on its use; that is, on how k_2 responds to changes in φ. As q falls in response to an increase in φ, and k_2 remains fixed, then emissions drop below E_0 and the emissions constraint is no longer binding. Given the assumption that the emissions constraint is always binding, the firm will wish to rearrange its operation so as to exploit the new-found slackness in this constraint. In Figure 2, (q^0, k_2^0) represents the initial situation. As φ increases, the firm wishes to reduce q in order to increase its profits. This is represented by the leftward movement away from the emissions constraint to q'. In moving back to the constraint, we see that the firm must reduce its use of k_2. Proposition 2 also ensures that the new optimal level of output q^1 will be less than q^0. The upshot is that an increase in φ leads to a decrease in output *and* a decrease in the use of abatement capital. The rate of return constraint is once again binding because while, as q falls and profits rise, at the same time, the use of k_1 and k_2 declines. In other words, the wedge between the two sides of the ROR constraint created by the increase in φ is eroded by increasing profits and a declining ratebase.

As long as the emissions constraint is binding, there is no direct impact on the environment. Thus there is no obvious reason to suppose that environmental lobbies prefer any given PUC strategy with respect to φ. One may speculate, however, that environmental lobbies prefer that all abatement capital be included in the ratebase. We have seen that such a policy leads to reduced output, and this has spillover effects in other industries. Lower levels of q imply lower levels of use of inputs, including coal and oil. Negative environmental externalities are associated with the production of many of these inputs. Thus, to the extent that there is a link between lower levels of production of these inputs and higher values for φ, environmental lobbies will prefer policies that include abatement equipment in the ratebase. An environmentalist, it seems, would be pleased to

[11] See the NARUC annual report of 1990. The lone exception, Tennessee, is also an exception in other ways. Almost none of its coal-burning plants are owned privately. Tennessee Valley Authority facilities, which are not beholden to the PUC in the same way that a private corporation would be, supply Tennessee with most of its electricity.

see $\varphi = 1$.

Finally, in this model, producers of pollution abatement equipment have a paradoxical incentive to lobby for the *exclusion* of abatement equipment from the ratebase. While, at the margin, an increase in φ makes abatement equipment more valuable to the utility, it also allows the firm to reduce output and optimally decrease its use of abatement equipment. To some extent, this result is an artifact of the assumption embedded in the model that the firm only uses abatement capital and/or output adjustments to control emissions. However, in fact abatement technology may be such that at any given output level the firm is able to achieve the same emissions level by trading off abatement capital against variable inputs such as fuel and labor. In this case, we speculate that increasing φ has confounding output and substitution effects on the demand for abatement equipment. The negative effect of a decrease in output will still exist but there will be a positive substitution effect as abatement capital's shadow price will fall relative to those of other abatement inputs. Thus, if abatement input substitution is feasible, the net effect of an increase in φ on the use of abatement capital depends on abatement input substitution elasticities.

In summary, even in a fairly simple model, the utility that faces both a rate of return constraint and a CAC environmental constraint must deal with a surprisingly complex decision problem. Our results show that the way in which the utility regulator treats pollution abatement equipment is a very important determinant of the firm's behavior. There is a tension, on the part of the PUC that seeks to enhance society's welfare position, between two powerful competing interests. Including abatement capital in the ratebase moderates the production inefficiencies that usually arise from ROR regulation. This frees up resources for uses that are now more profitable, and in a general equilibrium sense it makes society better off. However, setting $\varphi = 1$ appears to harm the welfare position of consumers of electricity by causing the regulated firm to reduce its output and charge a higher price. Whether the welfare effects in this market are larger than or smaller than the (partially offsetting) effects elsewhere in the economy is a question that lies outside the scope of this analysis. The deep paradox the attends regulatory treatment of environmental clean-up highlights the difficulties with regulation generally and with combinations of regulatory constraints in particular.

3. Allowance Trading and Utility Regulation

A regulated firm's decision problem grows more complicated when when it is augmented by an environmental constraint, but the fact that emissions are capped exogenously at E_0 helps to ease the decision-making burden. It is true that giving the firm additional latitude by allowing it to choose an emissions level, and then to enter a market for allowances, can reduce a firm's compliance costs. However, even in a fairly simple model the decision problem itself is much more complicated. In order to sort out the implications of the dual regulatory regimes in the presence of allowance trading, we first examine the firm's behavior when emission allowances can be traded, but there is no rate of return regulation. Then we consider the effects of rate of return regulation on these conditions and examine the effects of different regulatory treatment of emission allowance purchases upon the firm's choice of output, emission, and trading variables.

The 1990 Clean Air Act Amendments create a new commodity called an emission allowance, and seek to foster a national market in these allowances. Though electric utilities are asked to embrace the new allowance trading provisions, and are required by the law somehow to acquire them at a substantial expense, the property rights that inhere in an allowance are in some doubt. It appears, from Section 403(f) of Title IV, that future allowance allocations can be canceled by a future Congress.[12] The uncertainty that accompanies a purchase of allowances by virtue of this fact is likely to have complex effects on the allowance market. It seems clear that a utility's emission allowances, both those it is endowed with and those it purchases, are assets with lives of uncertain length. In practice, the capitalized value at which these assets trade will reflect that fact. Here, however, we assume that utilities believe emission allowances will exist in perpetuity and thus that, in a world of certainty, the price at which the allowances are leased, p_ℓ, divided by the market interest rate r is the acquisition price of an emissions asset (p_ℓ/r).

In the absence of rate of return regulation, under conditions of certainty, ownership of emission allowances provides the utility with no advantage over leasing allowances on a per period of time basis.[13] Thus, with no loss of generality, the firm is assumed initially to participate only in the lease

[12]The key language of Section 403(f) states that allowances "do not constitute a property right." According to Bumpers (1991), "Congress may rescind the right to receive allowances and this rescission would not amount to a taking. ... " Hahn and Hester (1989) have argued that uncertainty over property rights had been a leading culprit in the disappointing performance of earlier attempts at market based environmental control regimes.

[13]The firm may view ownership and leasing differently for many reasons that are not considered here. These might include differential tax treatment of capital acquisitions and operating expenses, as well as uncertainty about

market. The firm is endowed by the environmental regulator with an initial allocation of emission allowances L_0, and it may acquire or sell allowances in any amount at the current lease price p_ℓ (that is, the emission allowance market is competitive). The firm is required to have emission allowances equal to its actual emissions; that is, $e = \ell$, where e denotes emissions and ℓ denotes the quantity of emission allowances owned or leased by the firm. Thus the net cost of using emission allowances to satisfy its environmental constraint is $p_\ell(\ell - L_0)$.

Under these conditions, again employing the variable cost function $C(w, q, k_1)$, the firm now must choose three variables: k_1, k_2, and q. (Note that e is uniquely determined by these variables.) As before, the ROR constraint is assumed to be binding. We also assume that the firm will never hold excess allowances; that is, $e = \ell$.[14] Substituting the production function directly for q, and $h(q, k_2)$ for ℓ, the profit function may be written

$$\pi = p(q)q - C(w, q, k_1) - r(k_1 + k_2) - p_\ell(h(q, k_2) - L_0). \tag{3}$$

Note that in this specification the firm may make money on its allowance transaction. If $h(q, k_2) < L_0$ the firm is a net seller of allowances and the term $-p_\ell(h(q, k_2) - L_0)$ is an addition to profits. Without a ROR constraint, the firm is free to maximize (3) subject only to the nonnegativity constraints. The three first order necessary conditions for a maximum to (3) are given by

$$\partial\pi/\partial q = M(q) - C_q - p_\ell h_q = 0 \tag{4a}$$

$$\partial\pi/\partial k_1 = -C_{k_1} - r = 0 \tag{4b}$$

$$\partial\pi/\partial k_2 = -p_\ell h_{k_2} - r, = 0 \tag{4c}$$

where, for example, h_q denotes the partial derivative of $h(q, k_2)$ with respect to q, and where $M(q) = p + q\,p'(q)$ denotes the firm's marginal revenue.

Equation (4a) is simply the usual marginality condition for a pure monopoly seller: marginal costs must equal marginal revenue. Here, though, we include the marginal cost of environmental compliance as one component of marginal cost. Equation (4c), which implies that abatement costs will be equated across compliance strategies, is of particular interest. This expression may be

the future availability of allowances for lease.

[14] In a dynamic model of allowance trading, utilities may choose to overcomply with the environmental constraint in a given period in order to free up allowances for use at a later date. We ignore this possibility in our static model.

written $p_\ell = -r/h_{k_2} > 0$. The term $-r/h_{k_2}$ can be thought of as the marginal cost of reducing emissions via abatement capital. The marginal cost of complying with the law using allowances is simply p_ℓ, the allowance price. Equation (4c) therefore requires that in order to maximize profits the profit-maximizing firm equates the marginal cost of reducing emissions by using abatement capital with the price of an emission allowance; that is, it must minimize the cost of its compliance strategy.

In a competitive emission allowance market, in equilibrium, this result holds for all firms. Thus it implies economic efficiency in compliance technology; that is, marginal abatement costs, determined by the choice of k_2, will be identical across all firms. Differences in h_{k_2} across firms provide incentives for allowance trading that will remove those discrepancies. This is, in effect, the primary result of Montgomery (1972). It is also straightforward to show that in this case without ROR regulation, the firm will choose an efficient input mix: $f_x/f_{k_1} = w/r$. That is, production costs are minimized for any level of output.

When emissions trading is permitted between firms that face rate of return regulatory constraints the problem becomes more complicated. First, it is important to recognize that leasing allowances is no longer necessarily identical to purchasing allowances. To the extent that the asset market value of allowances is included in the ratebase, owning an allowance provides the utility with a ratebase enhancing advantage over leasing it. Users of allowances therefore have incentives to acquire permanent ownership of those allowances. In contrast, utilities with excess allowances have incentives to lease them rather than lose ownership. Here we assume that the allowances are sold; that is, users offer a sufficient (and sufficiently small) incentive to holders of surplus allowances so that they are indifferent between leasing those allowances or selling them.

Given that the lease price of an allowance is p_ℓ, then (as noted above) its acquisition price is p_ℓ/r. We assume that its acquisition price is the potential contribution of the emission allowance to the firm's ratebase. However, as was the case with abatement capital, the PUC may choose to allow none or only a part of this investment in the utility's ratebase. The fraction of emission allowance investment permitted in the ratebase is denoted θ, where we assume that $\theta \in [0, 1]$. Thus, a more liberal treatment of emission allowances for ratebase purposes is reflected by an increase in θ. If $\theta = 1$ then all investments in emission allowances are counted as part of the ratebase.

The possibility that emission allowances may be included in the ratebase is reflected in the following rate of return constraint:

$$\pi \leq (s-r)(k_1 + k_2 + \theta(p_\ell/r)\ell). \tag{5}$$

The fact is, as noted above, that almost all states allow all abatement capital to be included in the ratebase. Thus we assume throughout the remainder of the paper, as in equation (5), that $\varphi = 1$.[15] This specification of the constraint implies that no distinction is made for rate-making purposes between purchased allowances and those that were granted by the government. In fact, it now appears that there will be differences in these two categories of allowances—most notably by the IRS, for tax purposes—but we will not draw such a distinction here. While treating them differently might very well change the global solution to the firm's profit maximization problem it has no effect on the qualitative consequences of changes in PUC policy with respect to θ. Here we choose simply to treat allowances as allowances.

Using the assumptions that $q = f(x, k_1)$, that the firm chooses x efficiently given q and k_1, and that the firm does not hold excess allowances (so that $\ell = h(q, k_2)$), the firm's optimization program takes the form

$$\begin{aligned} \max_{q,k_1,k_2} \ \pi &= p(q)q - C(w,q,k_1) - r(k_1+k_2) - p_\ell(h(q,k_2) - L_0) \\ \text{s.t.} \quad \pi &\leq (s-r)(k_1 + k_2 + \theta(p_\ell/r)\ell). \end{aligned} \tag{6}$$

The lagrangian function for this program is given by

$$\begin{aligned} \mathcal{L}(q,k_1;\lambda) = {} & p(q)q - C(w,q,k_1) - r(k_1+k_2) - p_\ell(h(q,k_2) - L_0) + \\ & \lambda\big((s-r)(k_1+k_2+\theta(p_\ell/r)\ell - p(q)q + C(w,q,k_1) + r(k_1+k_2) + p_\ell(h(q,k_2)-L_0)\big), \end{aligned}$$

where $\lambda \geq 0$. The first order necessary conditions for a solution to (6) are given by

$$(p + qp'(q) - \partial C/\partial q - p_\ell h_q)(1-\lambda) + \lambda(s-r)(\theta p_\ell/r)h_q = 0 \tag{7a}$$

$$\partial C/\partial k_1 + r - \lambda((s-r) + \partial C/\partial k_1 + r) = 0. \tag{7b}$$

$$p_\ell h_{k_2} + r - \lambda((s-r) + (\theta p_\ell/r)h_{k_2}(s-r) + r - p_\ell h_{k_2}) = 0 \tag{7c}$$

$$p(q)q - C(w,q,k_1) - r(k_1+k_2) - p_\ell(h(q,k_2) - L_0) - (s-r)(k_1+k_2+\theta(p_\ell/r)\ell) = 0. \tag{7d}$$

[15] Thus, we ignore the important and interesting question of how a regulator seeking to maximize some measure of social welfare should jointly choose θ and φ.

The argument in section 2, following equations (2) above, may be used to establish that once again $\lambda \in (0,1)$. Using this result and combining (7b) and (7c), we may derive one of the three key results that were presented in the previous section for a firm that faces a CAC environmental constraint. This is that only when $\theta = 0$ will the ROR regulated firm will face the same incentives for selecting capital inputs that a pure profit-maximizing firm faces. If at least a part of ℓ is placed in the ratebase, then the utility is able to use allowances in the same way that it previously used abatement capital to exploit the allowed profit. Now, as ℓ is used in place of k_1 for purposes of profitably increasing the ratebase, the firm once again finds that it can move toward to an efficient (k_1, x) mix. Level curves of the constraint set in this problem are once again of finite slope unless $\theta = 0$. While this result will not be stated formally, a discussion that appears in the appendix establishes it informally.

Again an important question here is the nature of the firm's compliance strategy. The first order necessary conditions of the firm's optimization problem, slightly reformulated to include x as a decision variable rather than q, yield

$$p_\ell = -\frac{r}{h_{k_2}} \cdot \frac{r - \lambda s}{(1-\lambda)r - \theta(s-r)\lambda}. \tag{8}$$

Thus, the rate of return regulated firm maximizes profits by equating the price of an emission allowance with the marginal cost of abatement $-r/h_{k2}$ multiplied by the adjustment factor

$$\frac{r - \lambda s}{(1-\lambda)r - \theta(s-r)\lambda}, \tag{9}$$

which we claim is strictly less than one whenever $\theta < 1$. To see this, note from (7b) that $r - \lambda s > 0$. Adding and subtracting λs to the denominator, (9) can be written as

$$\frac{r - \lambda s}{r - \lambda s + \lambda(1-\theta)(s-r)}.$$

By assumption, $s > r$ and $\theta < 1$, and it has been noted that while the rate of return constraint is binding, $\lambda > 0$. Thus $\lambda(1-\theta)(s-r) > 0$, and the claim is established. It follows from (8) that if $\theta < 1$ and the rate of return constraint is binding then $p_\ell < -r/h_{k_2}$.

The above result shows that when none or only a part of the acquisition cost of an allowance is included in the ratebase, the firm maximizes profits when the price of using emission allowances

(p_ℓ) is smaller than the marginal cost of reducing emissions using abatement capital. Thus, when $\theta < 1$ the firm does not minimize the costs of its emissions compliance strategy.

The reason for this result is that when $\theta = 1$ there is no longer any difference between the effect of a unit of expenditures on emission allowances or abatement capital with respect to the firm's ratebase. When both φ and θ equal 1, the ratebase increases by the same amount whether the firm satisfies its emissions constraint by the same expenditures on either abatement equipment or the purchase of emission allowances. A similar result appears in Bohi and Burtraw (1991), who show that when expenditures on abatement capital and emission allowances are treated differently for purposes of ratebase determination firms will not minimize the costs of their emissions strategies.

It is also worth noting that if the rate of return constraint is not binding (that is, $\lambda = 0$), then again equation (9) implies that $p_\ell = -r/h_{k_2}$. Thus, if the firm is able to achieve its unconstrained level of profits, not surprisingly, it will pursue its unregulated emissions strategy.

A central concern of this paper is whether placing emission allowances in the ratebase increases the firm's demand for emission allowances. We now show that the effects are likely to be ambiguous; this suggests that the complex connection between ratemaking treatment and allowance market performance should be examined numerically. The above discussion indicates that as θ increases, given that p_ℓ and r are exogenous to the firm, the absolute value of h_{k_2} will increase. If output, q, is held constant, as θ increases an increase in h_{k_2} can occur only if the level of abatement capital is reduced. This follows from the assumption that $\partial^2 h/\partial k_2^2 > 0$—that is, for any given level of output, as the use of abatement capital decreases the marginal effect of abatement capital on emissions reductions rises. Thus, at any given output level, as θ increases emissions also increase and thus the quantity of emission allowances demanded by the firm increases. A rise in θ thus results in a substitution effect away from abatement capital towards emission allowances. However, there is no reason to believe that when θ is increased output will remain fixed.

Given an initial value for θ, say θ^0, at the optimal values for the choice variables, say q^0, k_1^0, and k_2^0 the rate of return constraint is assumed to be binding. If θ increases, then, at the original equilibrium the rate of return constraint is no longer binding. However, as before the profit function is strictly decreasing in output at q^0 (see the appendix) and thus the only way in which the firm can increase profits is to reduce output. The reduction in output, coupled with the fact that by (9) the absolute value of h_{k_2} will increase to a reduction in the use of abatement capital. The effect of an increase in θ on the demand for emission allowances, then, is ambiguous. The output effect will tend to reduce the quantity of emission allowances demanded by the firm while the substitution effect into allowances and away from abatement capital will tend to increase it.

Given that the effect of an increase in θ on the location of the individual firm's demand curve for emission allowances is indeterminate it is not possible to argue from "first principles" that the market price of emission allowances will rise or fall. The overall quantity of allowances supplied is fixed by government edict. However, whether an individual firm increases or reduces its demand for allowances depends on whether, for that firm, the positive substitution effect outweighs the negative output effect. The size of the substitution effect clearly depends on the firm's abatement technology and this technology differs across power plants (and therefore utilities). Thus, at any given allowance price, an increase in θ may cause some firms to increase their quantities demanded and others to decrease their quantities demanded. Therefore, whether the inclusion of investments in allowances in the ratebase will increase or decrease allowance prices is a question that awaits further analytical and empirical study.

Whether the quantity of allowances traded between utilities will rise or fall is also unclear. For purposes of illustration, suppose that only two utilities exist and that both are subject to the same PUC policy. Under the initial policy, when $\theta = \theta^0$, suppose that utility A has a positive excess demand for allowances ($\ell_A > L_A^0$) while utility B has a negative excess demand for allowances ($\ell_B < L_B^0$). The initial competitive equilibrium in the allowance market is illustrated in Figure 3 under the assumption that in relation to allowance prices the firms have well behaved excess demand and supply functions.

In Figure 3, ED_A^0 is A's initial excess demand function, ES_B^0 is B's initial excess supply function, p_ℓ^0 is the initial allowance price and ℓ^0 is the initial quantity of allowances traded. An increase in θ to θ^1 could well cause both A and B to reduce their demand for allowances resulting in downward shifts in both A's excess demand curve and B's excess supply curve to, say, ED_A^1 and ES_B^1 respectively. In the case illustrated in Figure 3, there is no change in traded quantity but the market price for allowances falls. However, it is quite possible that A's demand for allowances will rise while B's demand for allowances will fall. In that case (which does not appear in Figure 3), A's excess demand curve would rise, B's excess demand curve would fall and traded quantity would increase. However, the effect on allowance prices would be ambiguous and would depend on the relative movements of the utilities' excess demand and supply curves.

Finally, it is important to recognize that an increase in θ, by allowing firms to reduce output to increase profits, also increases electricity prices and reduces consumer surplus. Again, as in the command and control case, there is a clear conflict of interest between consumers of electricity and utilities with respect to PUC policy. The optimal policy from the perspective of the consumer (assuming the rate of return constraint is binding) is for the PUC to set $\theta = 0$. The utility maximizes its profits if $\theta = 1$.

If abatement capital is included in the ratebase (that is, if $\varphi = 1$), we conjecture that the social welfare consequences of setting θ equal to zero rather than one are ambiguous. When $\theta = 0$, consumers benefit from lower prices, but firms do not minimize either their compliance costs or their production costs. The full force of the A-J overcapitalization inefficiency comes into play, and firms rely too heavily on the use of scrubbers to come into compliance with the environmental constraint. If $\theta = 1$, compliance costs (in a locally optimal sense) are minimized and productive input mix distortions are mitigated, but consumer welfare is reduced.

We therefore agree with Bohi and Burtraw (1991), who have shown that if abatement capital and emission allowances are treated identically with respect to their inclusion or exclusion from the ratebase, utilities will behave efficiently in their emissions strategies. The results presented above indicate that consumer welfare is maximized if both abatement capital and emission allowances are excluded from the ratebase (that is, if both φ and θ are set equal to zero). In effect, by pursuing this policy, the PUC minimizes the adverse consumer welfare consequences of allowing utilities to earn rates of return in excess of competitive levels and provides the correct incentives for cost minimizing emissions programs.

4. Conclusions

The 1990 Clean Air Act Amendments constitute landmark environmental legislation. Title IV, the so-called acid rain title, requires massive reductions in SO_2 emissions. In addition, economic incentives in the form of marketable allowances will be used to achieve these reductions. Marketable permit schemes have been demonstrated to result in economically efficient compliance with environmental objectives when the polluting industry is perfectly competitive. However, the electric power industry operates under conditions that do not even closely approximate the competitive ideal; that is, firms in the industry are regulated monopolies. In this study, the familiar Averch and Johnson (1962) model of the rate-of-return regulated industry has been extended to account for the effects of both command and control environmental regulation and the introduction of marketable pollution allowances. The analysis has provided a series of new results that often appear to be counterintuitive.

Introducing an environmental constraint in the form of a CAC regulation has several consequences for economic efficiency and welfare. Applications of the theory of second best have frequently demonstrated that when economic agents face one set of distortionary incentives (as a result of market structure or government regulation), the introduction of another set of economic distortions may be welfare enhancing. Here, we have demonstrated that changes in the ratebase treatment of abatement capital lead to three important changes in the behavior of a regulated utility. First, an increase in the share of abatement capital investment permitted in the ratebase (φ) leads the firm to select a more efficient input mix. This result is due to a relaxation in the firm's profit constraint. Second, however, the same incentive leads the firm to reduce its output level, which increases electricity prices and lowers consumer welfare. Third, also because the firm reduces its output, it tends to reduce its use of abatement capital. The net social welfare effects, in a general equilibrium sense, of changes in the ratebase treatment of abatement capital are ambiguous.

When a CAC environmental constraint is replaced by an allowance trading market, the firm's compliance decision problem becomes more complicated. The firm must select optimal levels of output, abatement capital, *and sulfur dioxide emissions*. We have shown that in the absence of ROR regulation, the firm will adopt an efficient abatement strategy. When a binding ROR profit constraint is introduced and abatement equipment is included in the ratebase but allowances are not, the firm does not choose an efficient abatement strategy. The effects of admitting allowances into the ratebase have also been shown to resemble those that obtain when, under a CAC regime, abatement capital is included in the ratebase. First, the firm's productive input mix becomes more efficient. Second, it reduces output in order to increase profits, with an attending reduction in consumer welfare. In addition, when allowances are included in the ratebase, unambiguously, firms are shown to use less abatement capital. The effects on the quantity of emission allowances are ambiguous, involving a substitution effect away from abatement capital toward allowances, and an output effect that reduces emissions. Finally, when abatement capital is included in the ratebase, the full inclusion of allowances in the ratebase causes firms to adopt an efficient (cost-minimizing) compliance strategy. Again, these results indicate that changes in θ have ambiguous effects on net social welfare.

This study is based upon a model that quickly becomes complex analytically, but that captures only the basic elements of the decision problems that firms must solve in meeting the new requirements of the 1991 Amendments. We have restricted a utility's compliance strategies to three: reducing output, installing scrubbers, or purchasing allowances. In fact, there are many other choices that figure importantly in compliance planning decisions. One of these is switching fuels from high to low sulfur coal, which leads to reductions in emissions without the construction of expensive scrubbing equipment. There is also the purchase of power from non-coal burning sources, including nuclear and hydroelectric. Even a moderately large utility—one that owns several coal-burning units and perhaps a number of other generating facilities—must make its overall compliance decisions in an environment that is inherently stochastic. It would be very interesting to investigate the consequences of introducing uncertainty into the model, a difficult extension that has not been considered here.

Because of the difficulty that one faces in constructing meaningful analytical models that explain the allowance market, and in deducing the effects of various regulatory practices upon allowance prices and trading volumes, it would appear that numerical simulations would be another interesting extension of this study. This task is taken up in future work, but it is hoped that this study has provided a set of valuable insights into the complexities that accompany any effort to combine environmental and utility regulation.

APPENDIX

Before presenting the proof of Proposition 1, it will be helpful to develop a geometrical interpretation intuition of the Averch-Johnson model, and to expand upon the way that pollution abatement purchases affect the firm's decisions (this discussion draws upon Baumol and Klevorick 1970 and Bailey and Coleman 1971). It is easiest to work in (k_1, x) space, the space of productive inputs. The profit function, $\pi = p(q)q - wx - r(k_1 + g(q; E_0))$ (which can be expressed entirely as a function of k_1 and x with a suitable substitution of f for q) is strictly concave. The projection of its intersection with the ROR profit constraint onto the (k_1, x)-plane traces out a curve whose interior is a strictly convex set in R^2_+. This curve is the tear-shaped object labelled S in Figure 4; it consists of all productive input pairs that exactly satisfy the ROR constraint. Note that given k_1 and x (which together uniquely determine q), and given the function g (which together with q determines k_2), the firm's production plan is completely specified.

In the A-J world, the firm will choose a point that maximizes k_1 on the curve; this point is labelled A in Figure 4. The set of efficient (k_1, x) pairs (efficient in the sense that they minimize the cost of producing any given level of output with a given set of input prices) is represented by the dashed curve. The point P, at which an unregulated monopolist would maximize its profits, must lie along this curve. If the firm were to minimize the costs of producing the same output that is produced at A, it would move up and left along the isoquant q^A to point B. The famous A-J effect corresponds precisely to the difference between points A and B in this diagram. Point C is the only point that lies on S and that represents an efficient input mix.

The proof of Proposition 1 requires showing first that whenever $\varphi = 0$, a firm that faces ROR regulation will choose A, the same point that an A-J firm would choose, and second that for $\varphi \in (0, 1]$, the firm's input combination will be strictly between A and C along S.

PROOF OF PROPOSITION 1: Let the profit constraint be given by $\pi = (s - r)(k_1 + \varphi g(q; E_0))$. The firm will choose an input mix so as to equalize the slope of a level curve of this constraint and S. The slope of a level curve may be found by totally differentiating the constraint, and setting the result equal to zero. This derivative is given by

$$0 = (s - r)dk_1 + (s - r)\varphi g'(q)(f_x dx + f_{k_1} dk_1), \tag{A1}$$

where f_x and f_{k_1} denote the partial derivatives of f with respect to x and k_1 respectively. Equation (A1) may be rearranged to yield

$$\text{(A2)} \qquad \frac{dx}{dk_1} = -\frac{1+\varphi g'(q) f_{k_1}}{\varphi g'(q) f_x} = -\frac{f_{k_1}}{f_x} - \frac{1}{\varphi g'(q) f_x} < 0.$$

From equation (A2), a level curve of the constraint is negatively (and finitely) sloped for any $\varphi > 0$, while this slope goes to negative infinity as $\varphi \to 0$. That is, for $\varphi = 0$, the firm will choose the rightmost point on S. This result is also apparent, using Averch and Johnson's own development, once it is noticed that the constraint becomes simply $\pi = (s-r)k_1$ when $\varphi = 0$.

To show part *ii.*, note that the unregulated monopolist will choose an input combination at which $dx/dk_1 = f_{k_1}/f_x = -r/w$. Equation (A2) can only satisfy this equality if the term $(\varphi g'(q) f_x)^{-1}$ vanishes, but for finite and strictly positive (k_1, x) pairs the two derivatives are finite, and it is always true that $\varphi \leq 1$. Thus, at the optimal input combination $dx/dk_1 <\mid f_{k_1}/fx \mid$.

Finally, we must show that the optimal input combination will be somewhere above and to the left of the point A along S. Let $U^{\pi}(\varphi) = \{(k_1, x) \in R^2_+ \mid (s-r)(k + \varphi g(q)) > \pi\}$. This set may be thought of as the upper contour set of π for a given φ. Now, by way of contradiction, suppose that with $\varphi > 0$ the firm were to choose a (k_1, x) pair D so that $k_1^A > k_1^D$ and $x^A > x^D$ (see Figure 4). This implies that $U^{\pi}(\varphi) \cap \text{cl}(S) \neq \emptyset$, where $\text{cl}(S)$ is simply the closure of a set S. Clearly, there are elements of S in this intersection, which means that there exist input pairs that satisfy the rate of return constraint and that yield higher profits than point D. This contradicts the assumption the point D was optimal, and we conclude that the optimal point is above A. This completes the proof of Proposition 1. ∎

The proof of Proposition 2 proceeds in two steps, the first of which is to prove the following lemma establishing that at the optimal pair (q^*, k_1^*), profits are declining in output.

LEMMA 1. *Under the hypotheses of Proposition 2, the firm's profit function is declining in q at (q^*, k_1^*).*

PROOF OF LEMMA 2: The firm's profit function is $\pi = p(q)q - C(w, q, k_1) - r(k_1 + g(q))$, and the derivative of this expression with respect to q is $\partial\pi/\partial q = M(q) - \partial C/\partial q - rg'(q))$, where

$M(q) = p + qp'(q)$ is marginal revenue. Combining this expression with (2a), we see that

$$\text{(A3)} \qquad \frac{\partial \pi}{\partial q} = M(q) - \partial C/\partial q - rg'(q) = -\frac{\lambda(s-r)\varphi g'(q)}{(1-\lambda)}.$$

Equation (2d) yields

$$\text{(A4)} \qquad \frac{\lambda}{(1-\lambda)} = \frac{\partial C/\partial k_1 + r}{(s-r)}.$$

We are through if it can be shown that $\partial \pi/\partial q < 0$. Combining (A3) and (A4), we have

$$\frac{\partial \pi}{\partial q} = -(\partial C/\partial k_1 + r)\varphi g'(q) < 0,$$

which was to be shown. We conclude that, because profits are declining in q, an increase in profits can be accomplished only by reducing output. This completes the proof of Lemma 1. ∎

Proof of Proposition 2: Referring again to Figure 4, we will provide a geometrical and heuristic proof of Proposition 2. Note that in the A-J model, one may examine the movement of output and productive input combinations as s increases. This increase, when r is held fixed, simply increases the slope of the constraint plane that traces out S. If $\varphi = 0$, then our ROR profit constraint is identical to the A-J constraint—it is a plane in 3-space. When φ becomes positive, and then increases, the constraint is no longer a plane, but rather a curved surface lying above the $\pi = (s-r)k_1$ plane. The distance between these two objects grows as φ increases, and the set of points in 3-space satsifying $\pi = (s-r)(k_1 + \varphi g(q; E_0))$ "curls up" and passes through the profit surface.

Given a value for φ, the firm's optimal choice of k_1 and x will be found where a level curve of the constraint surface has the same slope as the profit function in (k_1, x)-space. This fact was used in the proof of Proposition 1. Proposition 1 also showed that the optimal input combination with ROR and environmental regulation will never be northwest of the set of efficient input bundles (the dashed line in Figure 4). Thus, as φ increases, the firm's input bundle moves leftward and downward, away from point A and always staying below the dashed line. For reasonable restrictions on the slopes of isoquants, this would appear to rule out having the optimal input bundle move outward to isoquants that correspond to higher output.

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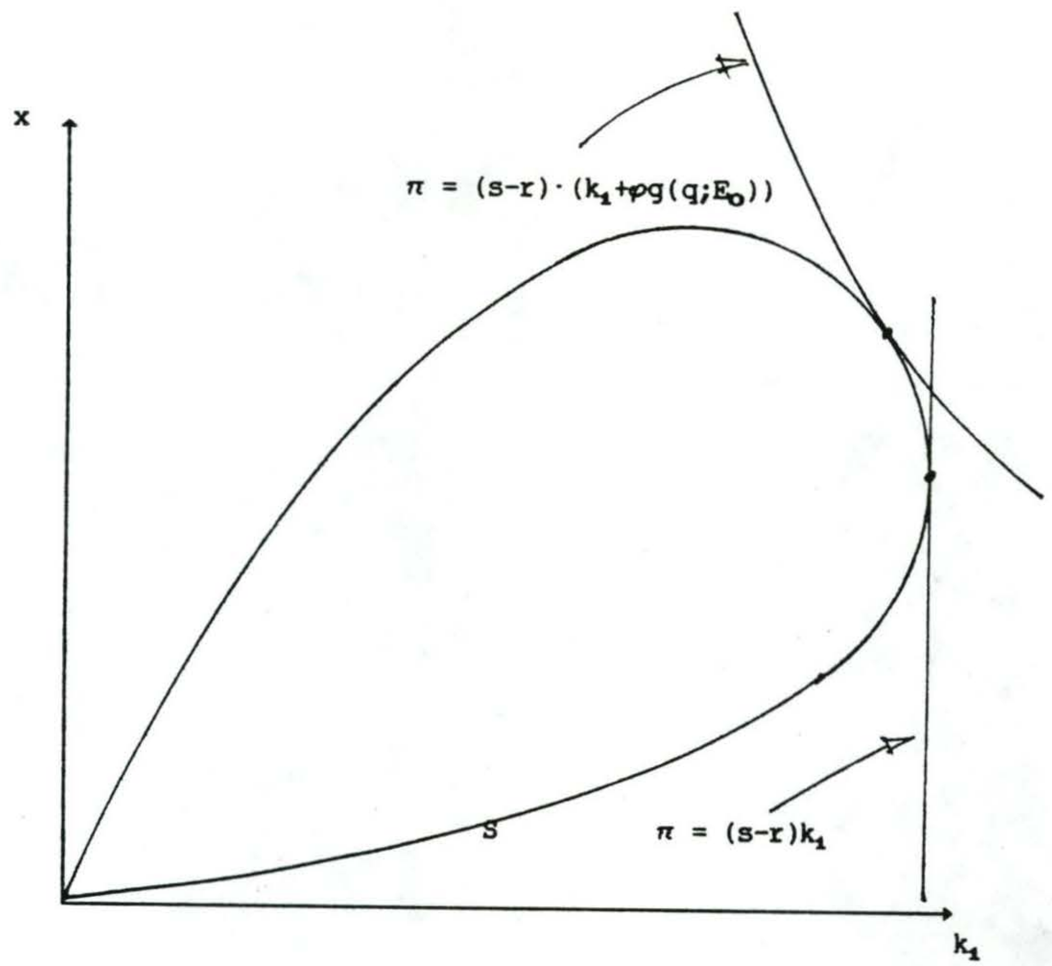

Figure 1. Optimal input choices under rate of return and environmental regulation.

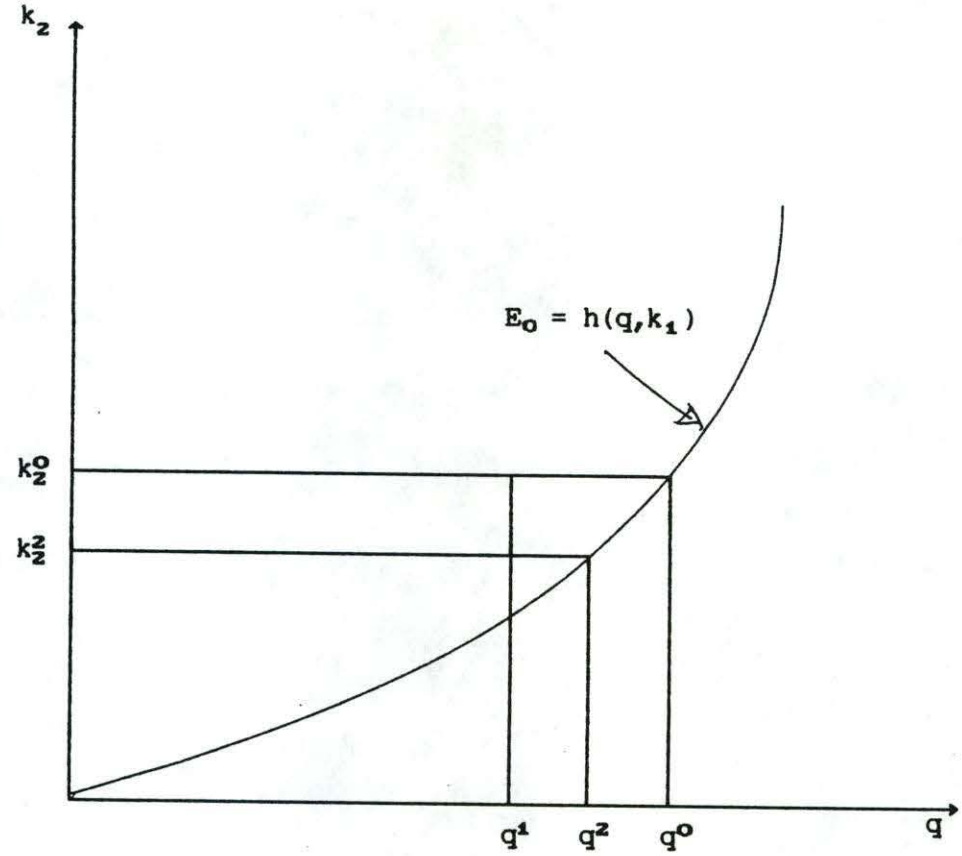

Figure 2. Output response to changes in φ.

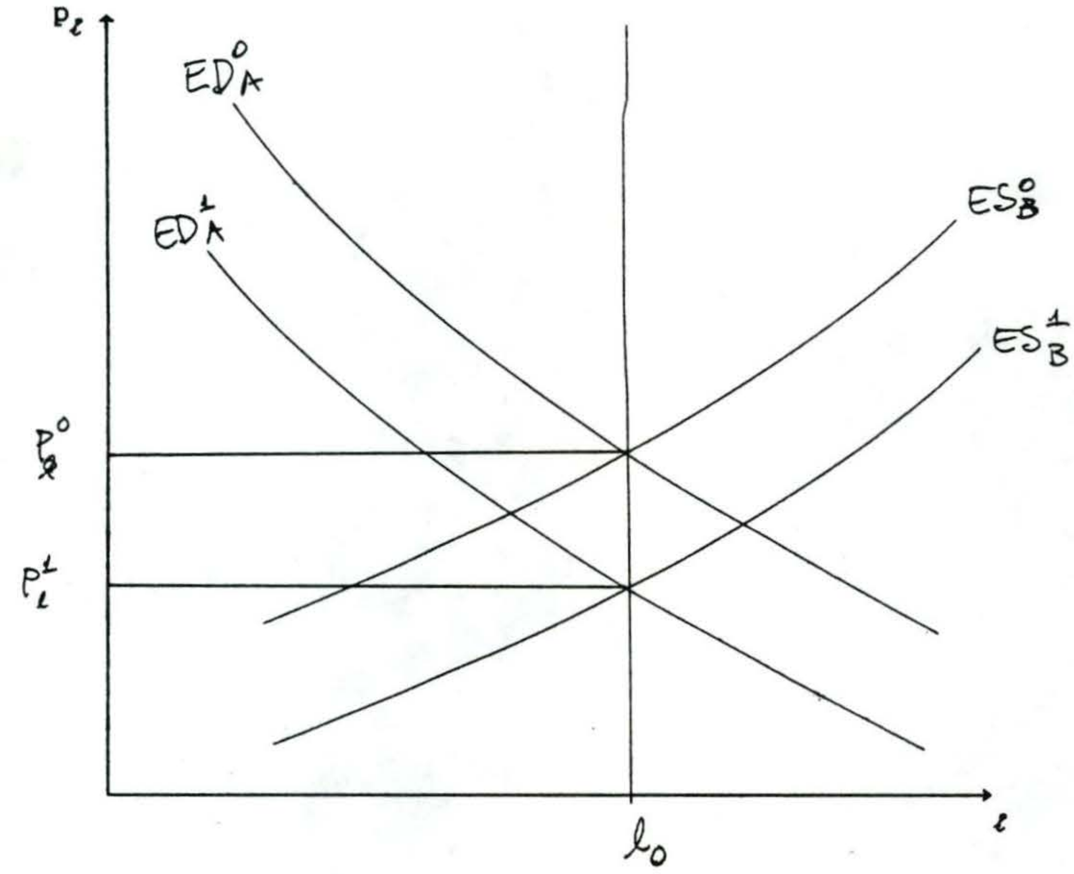

Figure 3. Demand and supply response to changes in θ.

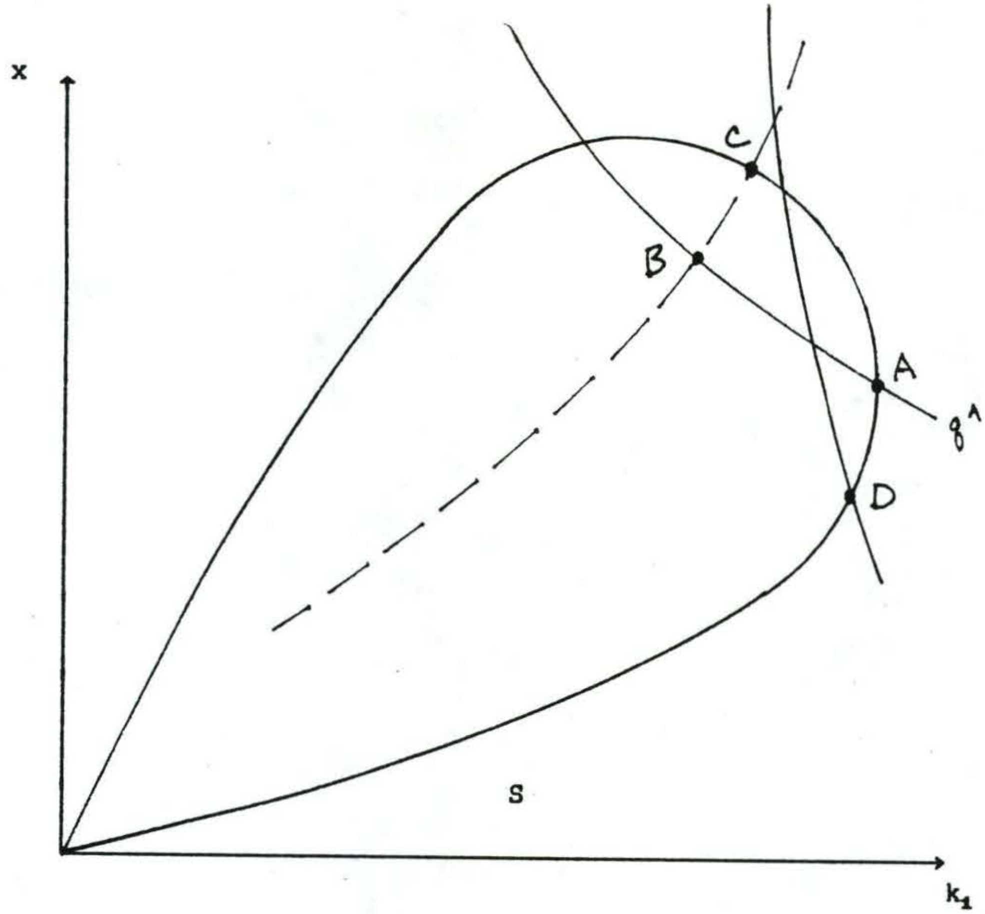

Figure 4. Optimal input choice under rate of return and environmental regulation.