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Markets and Regulatory Hold-Up Problems*

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Many regulatory programs such as environmental regulation are effective only if firms make irreversible investments that reduce the cost of compliance A firm potentially subject to regulation may therefore behave strategically by not investing, thereby forcing the regulator to void the proposed regulation. We show that such incentives, which resemble a hold-up problem, may not be overcome when government's only tool is the imposition of an emissions tax. The hold-up problem can be overcome by the issuance of tradeable permits. A time-consistent equilibrium exists with all firms investing and the government imposing regulations, even if no permits are traded and their market price is low. Indeed, an observation of no trade may indicate that pollution abatement is great

1. INTRODUCTION

Many governmental programs are effective only if firms make some costly investment. The problem is widespread, but for concreteness we shall speak of environmental regulation. We may consider the installation of scrubbers by electrical utilities, of R & D expenditures by automobile manufacturers to reduce emissions by vehicles, of the construction of refinery equipment to produce unleaded gasoline, or of the installation of water-cleaning equipment by chemical manufacturers. To give more specific examples, the Energy Policy and Conservation Act of 1975 required firms to increase the fuel efficiency of the cars they produce, which called for investments in tools to produce front-wheel-drive vehicles, research and development into lighter weight materials, and so on. The 1970 Amendments to the Clean Air Act were explicitly technology-forcing, calling for 90% reductions in emissions by 1975, a goal that was unachievable with 1970 technology.[1] Regulatory programs which require firms to invest may be subject to a time-inconsistency problem caused by the strategic behavior of firms. A firm may choose not to invest, thereby both keeping its costs low and inducing the government to abandon its

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[1] For work on investments, see Milliman and Prince [14] and Jung, Krutilla, and Boyd [7], who examine the incentives of firms to invest in new technology under different regulatory methods Laffont and Tirole [10] show that simple markets for pollution permits reduce incentives for innovation, and propose that options to pollute are a better policy. Requate [16] considers output markets and shows that permits allow for partial adoption of new technologies while taxes do not

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plan of imposing regulations. That is, a firm potentially subject to regulation may recognize that if it does not invest, then government may find it best not to enforce the regulation.

In this paper, we show that such incentives, which resemble a hold-up problem, may not be overcome when government's only tool is the imposition of an emission tax. The hold-up problem can be overcome by the issuance of tradeable permits if more than two firms operate in the same industry. A time-consistent equilibrium can exist with all firms investing and the government imposing regulations, even if no permits are traded and their market price is low. Indeed, an observation of no trade may indicate that pollution abatement is great.

2. FURTHER EXAMPLES OF COMMITMENT PROBLEMS

In this section we provide further examples for the commitment problem of regulators. Consider regulatory programs to reduce automobile emissions. Suppose firms did not invest and thus could not meet the standards. Enforcing the standards would effectively forbid the sale of new cars, would close down factories, and would throw hundreds of thousands of workers out of work. The harshness of the threat makes it not credible. But if the threat is not credible, then firms will not invest.

The automobile manufacturers recognize such incentives.[2] Faced with concerns about pollution in southern California, the automobile companies responded that pollution was a tough problem requiring additional research. But they did little research. Instead, in 1955 they signed a cross-licensing agreement giving each firm royalty-free rights to any patents on emission equipment—no firm had an incentive to engage in research. This agreement was challenged in 1969 by the U.S. Department of Justice, which claimed that the manufacturers colluded to delay the development of emission control technology. The breakthrough in emission control came in 1963 when California enacted a law requiring the installation of emission controls 1 year after the state certified that two devices were practical and available at reasonable cost. Equipment manufacturers took up the challenge, and in 1964 the automobile manufacturers announced that they would install emission controls in new cars.

Later regulation continued to suffer from credibility problems. The standards specified by the 1970 Clean Air Act were repeatedly delayed. Most dramatically, faced with industry claims that the current emission standards would shut down factories, Congress amended the Act in 1977, weakening and postponing the standards. Similarly, in 1988 the government delayed standards for the 1989 model year.

Another example illustrates credibility problems. In 1998 Congress included a provision in the highway bill which would put off for 6 to 9 years the first steps to bring states into compliance with the Clean Air Act's longstanding goal of "reasonable progress" toward eliminating man-made haze in specially protected areas. Until Congress intervened, the Environmental Protection Agency had planned to tell states to file preliminary plans by 1999 showing how they would eventually comply with new rules proposed last year that would raise visibility standards gradually over the next several decades.[3]

[2] This paragraph is based on White [23].

[3] See New York *Times*, May 27, 1998.

While credibility is often a problem for regulators, they can sometimes commit to certain policies. If the president and Congress belong to different political parties, then changing legislation may be difficult. When environmental groups can sue in the courts to force the regulatory agency to implement the law, the credibility becomes yet stronger.[4] In addition, as pointed out by Amacher and Malik [1] a regulator has an incentive to develop means to commit himself to an instrument.

3. RELATION TO THE LITERATURE

The essential idea that threats or promises by government may not be credible appears in some important work on trade protection (Staiger and Tabellini [18], Matsuyama [13], Tornell [19]); regulation of utilities (Salant and Woroch [17], Gilbert and Newbery [4], Urbiztondo [20]); and privatization (Levy and Spiller [11]). These analyses relate to the hold-up problem—a firm facing a single buyer may find investment unprofitable if, after making the investment, the buyer will offer to pay only marginal cost (see Klein, Crawford, and Alchian [8], Joskow [5], Williamson [24]).

Our analysis also relates to models of mechanism design that use the tools of multistage games and subgame perfect equilibria (see Varian [22] or Moore [15] for a review of the literature). We show that tradeable permits, a regulatory mechanism that has been favored for reasons unrelated to credibility, may solve the hold-up problem. Indeed, whereas the usual justification for permits (the opportunity for firms with low abatement costs to abate more than firms with high costs) requires that firms differ and that trades are made in equilibrium, we show that marketable permits can be effective even if all firms are identical and no permits are traded. It is important, however, that agents anticipate that trading occurs for out-of-equilibrium actions.

Finally, our paper relates to the literature on environmental regulation and to the work on strategic considerations of firm behavior (Yao [25], Malik [12], Biglaiser, Horowitz, and Quiggin [2]). Yao [25] examines the dynamics of technology-forcing regulations given technological uncertainty and asymmetric innovation about innovation capacities. He finds that the initial level of R & D activity caused by regulation increases with the intrinsic technical capability of the industry. Malik [12] compares permanent and interim regulation when a regulator anticipates learning about the benefits or costs of regulations over time. He shows that neither policy is first best. He also identifies conditions under which one policy dominates the other one. Biglaiser, Horowitz, and Quiggin [2] address the time inconsistency of optimal permit regulation. They show that tradeable pollution permits may not achieve the social optimum because firms behave strategically against the regulator.

[4] But litigation is not assured. For instance, the U.S. legislation covering the sulfur dioxide trading program states that emissions permits are not property rights (Laffont and Tirole [10]). Hence, issuing new permits ex post does not amount to a regulatory taking and the owners of permits may be unable to sue a government in a court of law.

While these models consider the game between an industry or a representative firm with the regulator, we consider an oligopoly of firms facing a regulator.[5] Moreover, we require that regulation be time-consistent and credible at every point in time. The paper's contribution thus lies in considering how a single firm's decisions can affect the policy government adopts for the whole industry.

A firm that invests in abatement weighs the following considerations. First, the investment may cause government to impose the regulation which it would not if this firm had not invested. Second, a firm that invested may gain from selling pollution permits to firms that did not invest. The magnitude of these effects will depend, *inter alia*, on the number of other firms that invest. We thus examine equilibria in which firms make investment decisions strategically: they take into account how other firms decide on their investments and how government policy is affected by the firms' investment decisions.

As will be seen, an equilibrium can appear in which all firms invest when the following chain of events occurs: a firm's investment induces government to allocate permits (corresponding to the socially optimal level of emissions given the investments firms made), and the investing firm can then sell permits to firms that did not invest (they would buy the permits rather than abate because a firm that did not invest faces a high marginal cost of abatement). A solution with no firm investing may therefore not be an equilibrium, while a solution with all firms investing can be a subgame perfect equilibrium. Emission taxes will be seen to be less suitable in solving the hold-up problem. A firm that invested would incur the cost of investment, would have to incur abatement costs, and would have to pay taxes for the remaining emissions. Therefore, incentives to invest are lower under emission taxes than with marketable permits.

Finally, our paper is related to work about incentives to adopt less polluting technologies in the design of environmental policy instruments. Milliman and Prince [14] and Jung, Krutilla, and Boyd [7] examine the incentives of firms to invest in new technology under different regulatory methods and provide a ranking of different policy instruments. Laffont and Tirole [10] show that simple markets for pollution permits reduce incentives for innovation, and propose options to pollute as a better policy. Requate [16] considers output markets and shows that permits allow for partial adoption of new technologies while taxes do not. Requate and Unold [16a] challenge the general presumption that permit markets provide higher incentives to innovate than taxes (see also [2a]).

4. MODEL

Consider the following four-stage mechanism.

Stage 1. Firms decide whether to make an investment that allows them to later reduce emissions. The investment is lumpy and sunk, costing K to each firm. Call a firm that has invested a "prepared" firm.

Stage 2. Government observes the investment of firms. It then imposes identical regulations on the firms: each firm must either abate by a certain

[5] An exception is Biglaiser, Horowitz, and Quiggin [2] They also allow firms to influence the amount of permits issued by regulator, which in turn affects the costs of buying permits for other firms However, they consider marginal investment changes that do not allow efficient firms to obtain large profits by selling permits to polluting firms

amount or hold permits for the unabated emissions. Government allocates emission permits equally to each firm.[6]

Stage 3. Prepared firms reduce emissions.

Stage 4. Firms trade emission permits.

While Stages 1 and 2 occur sequentially in time, Stages 3 and 4 occur simultaneously.

Firms and government all have perfect information. Each firm therefore anticipates what government does for any set of investment decisions.[7]

The key assumption about commitment that (1) the regulator is unable to commit to the stringency of the policy instrument, and (2) the regulator can commit to issue marketable permits.[8]

4.1. *Notation*

K_i	Investment costs of firm i, $K_i = \begin{cases} K & \text{if firm } i \text{ prepares,} \\ 0 & \text{if firm } i \text{ remains unprepared} \end{cases}$
n	Number of firms
v_i	Abatement by firm i, $v_i = 0$ for an unprepared firm
l	Number of prepared firms $l \in \{0, 1, \ldots, n\}$
f^0	Emission by a firm that did not invest
$C(v_i)$	Costs of reducing emissions by v_i
$D(nf^0 - \Sigma v_i)$	Social damages from emissions
$Q(l)$	Amount of emission permits issued by the regulator, depending on the number of firms, l, which invested
p	Price of an emissions permit
W	Social costs, $W = D(nf^0 - \Sigma v_i) + \Sigma_{i=1}^{n} C(v_i) + \Sigma_{i=1}^{n} K_i$

For simplicity, we focus on investment to reduce emissions, and we take production capacity and output as fixed. We therefore suppose that each firm produces one unit of the good at a fixed price.

The cost of emissions reduction in the amount v by a prepared firm is $C(v)$. The social costs from emissions x are $D(x)$. These functions are assumed to satisfy

1. $C' > 0$; $C'' > 0$
2. $D' > 0$; $D'' \geq 0$

[6] As stated in the previous footnote, the assumption of equality is not critical A critical assumption is that a prepared firm receives at least as many permits as an unprepared firm

[7] The government adjusts the level of pollution allowances depending on how many firms invested. Thus, the inefficiencies of simple pollution markets for environmental innovation, discussed in Laffont and Tirole [9], do not occur.

[8] In our model the regulator's policy is time consistent. But under different assumptions it need not be Suppose, for example, that the regulator may have revenue objectives in the future Then he may have an incentive to opt for emission taxes in future periods. If firms anticipate that the government could have future revenue objectives, the possibilities to solve the hold-up problem are smaller

Social benefits from the output are supposed to be sufficiently great so that even without abatement the regulator never wants to reduce output. Hence, the threat to shut down a firm that does not invest is not credible and cannot be used to induce investment.[9]

At the beginning of the game all firms are identical. This represents a strong departure from typical analyses of tradeable permit schemes, which usually require heterogeneity of firms in order to generate gains from trade.

4.2. *Social Optimum in Stage 2*

A socially optimal solution is characterized by two variables: the number of firms that invest, l, and the level of abatement by each prepared firm, v. Let emissions by a firm with zero abatement be f^0: these are emissions by any unprepared firm, and by any prepared firm which sets $v = 0$.

Consider first the social optimum when l firms invest. From the assumption that $C' > 0$ and that $C'' > 0$ it follows that minimizing abatement costs requires prepared firms to abate in equal amounts. The first-order condition is[10]

$$D'(nf^0 - lv) = C'(v). \tag{1}$$

Let $v(l)$ solve the social welfare problem, which solution is assumed to be unique. Our assumptions imply that

LEMMA 1. *$v(l)$ weakly decreases monotonically in l.*

Clearly, the greater the number of firms that invested, the less any one firm needs to reduce emissions. Let $W(l)$ be social costs when l firms invest and the socially optimal abatement levels $v(l)$ are implemented. Then

$$W(l) = D(nf^0 - l \cdot v(l)) + l \cdot C(v(l)) + l \cdot K. \tag{2}$$

In the following assume that

$$W(n) < W(n-1) \cdots < W(1) < W(0). \tag{3}$$

Hence social optimality requires all firms to invest.[11]

4.3. *The Markets for Emission Permits*

The government observes how many firms have invested, and then sets the number of permits at

$$Q = nf^0 - l \cdot v(l). \tag{4}$$

[9] The analysis can, however, also apply when the government auctions a portion of the permits corresponding to the number of permits prepared firms need multiplied by the number of firms If, however, the regulator sells all permits. the gains for prepared firms from offering permits to unprepared firms would disappear and hence it would become more difficult to overcome the hold-up problem

[10] We assume the second-order condition is fulfilled and that the solution is unique

[11] If it were not socially optimal to have all firms invest, marketable permits could result in overinvestment For more details see Gersbach [3]

Put differently, all but $lv(l)$ units of emission are covered by permits; the firms must abate, in the aggregate, in the amount $lv(l)$.

Permits are allocated equally among firms, so that each firm receives an allocation of

$$\frac{Q}{n} = f^0 - \frac{l}{n} \cdot v(l).$$

By assumption for an unprepared firm can reduce emissions only by reducing output. That would reduce expenses for permits, but would reduce revenue. In the following, we assume that the market price of an emission permit for any positive number of investing firms is lower than marginal losses from reducing emissions by reducing output. Hence, unprepared firms will demand,

$$\frac{l}{n} \cdot v(l),$$

additional permits to meet their emission requirements. Aggregate demand for emission permits is therefore,

$$(n - l) \cdot \frac{l}{n} \cdot v(l).$$

Consider the supply of emission permits by a prepared firm. Let p be the market price of a permit. Because the number of firms need not be large, each firm may have market power in determining the price of permits. Investment will be most attractive if a firm can sell permits at a high price (say by extracting revenue determined by a buyer's all-or-nothing demand curve); it will be least attractive if the firm can earn little revenue. If there are few firms on both market sides, very different price equilibria can exist in the permit market (Gersbach [3]). In the following, we focus on the competitive equilibrium. This can be justified by two reasons. First, any equilibrium in the permit market must involve prices equal to or above the competitive price. The competitive equilibrium is the least attractive for prepared firms. Any other type of equilibrium would only strengthen our results.

Second, the government can ensure that the competitive equilibrium results by influencing the strategic behavior of prepared firms through supplementing the supply. This is a common practice in part of the environmental regulation in the United States, in particular for controlling sulfur dioxide. If the government supplements the supply of permits to the competitive supply curve, given that l firms have invested, no prepared firm gains by deviating from price-taking behavior in the permit market.[12] Holding back with permits would simply be compensated by an additional supply of the government. Given that a firm cannot gain by deviating from price-taking behavior, a prepared firm, say firm i, solves the following problem,

$$\max\left(p \cdot \left(f^0 - \frac{l}{n} \cdot v(l) - (f^0 - v_i)\right) - C(v_i)\right)$$

$$= \max\left(p \cdot \left(v_i - \frac{l}{n} \cdot v(l)\right) - C(v_i)\right). \qquad (5)$$

[12] Any other supplement strategy would only strengthen the results of the paper [see Gersbach [3] for a treatment of other regulatory supplement strategies]

Hence, a prepared firm i sets v_i to satisfy $p = C'(v_i)$. Denote the solution by $\bar{v}_i(p)$. Then the supply of permits by a prepared firm is

$$S_i = \bar{v}_i(p) - \frac{l}{n} \cdot v(l). \tag{6}$$

Aggregate net supply of permits by prepared firms is

$$S = l \cdot \bar{v}_i(p) - \frac{l^2}{n} \cdot v(l). \tag{7}$$

Equilibrium in the market for permits requires

$$\begin{aligned} (n - l) \cdot \frac{l}{n} \cdot v(l) &= l \cdot \bar{v}_i(p) - \frac{l^2}{n} \cdot v(l), \\ (n - l) \cdot v(l) &= n \cdot \bar{v}_i(p) - l \cdot v(l). \end{aligned} \tag{8}$$

We thus obtain

$$\bar{v}_i(p) = v(l) \quad \text{and} \quad p = C'(v(l)). \tag{9}$$

Let $p(l)$ be the market price of a permit when l firms invest. Because $v(l)$ decreases with l, we obtain

LEMMA 2. $p(1) \geq \cdots \geq p(n)$.

4.4. *Equilibrium*

We characterize the subgame perfect equilibria in the four-stage game by establishing the following propositions:

PROPOSITION 1. *Suppose $n = 1$. Then, a unique subgame perfect equilibrium exists: The firm does not invest and the regulator issues,*

$$Q = f^0$$

permits.

The proposition follows immediately from our assumptions. Because the unprepared firm cannot be credibly threatened with regulation, the firm minimizes costs by not investing. The system of marketable permits cannot help to alleviate the investment incentives. The situation is different if more firms are present in the market.

PROPOSITION 2. *Suppose that $n \geq 2$ and*

$$\frac{n-1}{n} \cdot v(n-1) \cdot p(n-1) > K + C(v(n)). \tag{10}$$

Then there is an equilibrium in which all firms invest and government sets

$$Q = n \cdot f^0 - n \cdot v(n). \tag{11}$$

Prepared firms set $v_i = v(n)$.

Proof. If one firm deviates by not investing, while the other $n-1$ firms invest, its cost of buying permits is

$$\frac{n-1}{n} \cdot v(n-1) \cdot p(n-1).$$

If the cost of permits is greater than the cost of investment (that is, if (10) is satisfied), the firm will find it unprofitable to deviate. Hence, if all firms invest, no firm deviates and the strategies described are an equilibrium. Because Q is the level of emissions that maximizes social welfare, the government finds it optimal to limit emissions and to issue permits in Stage 3. Hence, the equilibrium is subgame perfect. Q.E.D.

Condition (10) in the proposition has a straightforward interpretation. The firm anticipates the regulator's reaction to a change in the number of investing firms and calculates the costs of buying permits in if it does not invest. Finally, these costs are compared with the cost of investment. Whether the condition is fulfilled depends crucially on the properties of the cost function.

4.5. *An Example*

Condition (10) defines the parameter region in terms of the number of firms, social costs of emissions, costs of emission reductions, and preparation investment for which there is a solution to the hold-up problem. To illustrate the solution region, consider a simple example,

$$D(nf^0 - lv) = a(nf^0 - lv),$$
$$C(v) = \frac{b}{2}v^2,$$

where a and b are two positive constants. Hence, social damage is linear in the amount of emissions. Given that l firms have invested social optimum yields $a = bv$ or

$$v(l) = \frac{a}{b}, \qquad l = 1, \ldots, n.$$

Because social costs are a linear function of the level of emissions, the social optimum requires that a prepared firm abates by a/b, irrespective of how many firms have invested. Using

$$p(n-1) = C'(v(n-1)) = bv(n-1) = a,$$

condition (10), which describes the hold-up solution condition, amounts to

$$\frac{n-1}{n} \cdot \frac{a}{b} \cdot a > K + \frac{b}{2}\left(\frac{a}{b}\right)^2,$$

or

$$\frac{n-2}{n} \frac{a^2}{2b} > K.$$

Hence, we obtain:

COROLLARY 1. *Suppose $D(x) = ax$ and $C(v) = (b/2)v^2$. Then, there exists an equilibrium in which all firms invest if*

$$\frac{n-2}{n}\frac{a^2}{2b} > K.$$

Note that the condition is easier to fulfill if marginal social cost of emissions is high, the marginal cost of abatement is low, the number of firms is high, and preparation costs are low. For any set of parameters $\{n, a, b\}$ the hold-up problem can be solved if K is sufficiently small and $n > 2$.

4.6. *Uniqueness*

We also provide necessary and sufficient condition for uniqueness of the full investment equilibrium.

PROPOSITION 3. *The equilibrium in which all firms invest is unique if and only if*

$$\min_{l \leq n-1}\left(\frac{n-l-1}{n}\cdot v(l+1)\cdot p(l+1) + \frac{l}{n}\cdot v(l)\cdot p(l) - C(v(l+1))\right) > K. \tag{12}$$

Proof We show that the outcome with only $l < n$ firms investing is not an equilibrium if condition (12) holds. Suppose $l < n$ firms have already invested. An unprepared firm would purchase permits at a cost of

$$\frac{l}{n}\cdot v(l)\cdot p(l). \tag{13}$$

If this firm invests it can sell emission permits and it can earn

$$\left(v(l+1) - \frac{l+1}{n}\cdot v(l+1)\right)\cdot p(l+1) = \frac{n-l-1}{n}\cdot v(l+1)\cdot p(l+1). \tag{14}$$

If the sum of expressions (13) and (14) exceeds the investment costs and abatement costs, the firm profits from investing: the outcome with only $l < n$ firms investing is not an equilibrium.

We also claim that the condition in the proposition is necessary. For proof we first consider $l = 0$ as a possible equilibrium. A firm that had invested would gain revenue from selling permits of

$$\frac{n-1}{n}\cdot v(1)\cdot p(1).$$

Hence, a firm would invest given that no other firm invests if

$$\frac{n-1}{n}\cdot v(1)\cdot p(1) > K + C(v(1)).$$

When $l = 0$, the expression (12) of the proposition is reduced to the previous inequality.

Consider next $l = 1$ as a possible equilibrium. That outcome is not an equilibrium if the investing firm has an incentive not to invest or if noninvesting firms want to invest. No firm would invest if

$$\frac{n-1}{n} \cdot v(1) \cdot p(1) < K + C(v(1)),$$

which, however, is ruled out by condition (12) for $l = 0$.

An equilibrium with $l = 1$ would not exist if an additional firm profits from investing. A second investing firm earns revenue from the sale of permits of

$$\frac{n-2}{n} \cdot v(2) \cdot p(2),$$

and would have costs of purchasing permits in the amount,

$$\frac{1}{n} \cdot v(1) \cdot p(1).$$

Overall, this firm profits from investment if

$$\frac{n-2}{n} \cdot v(2) \cdot p(2) + \frac{1}{n} \cdot v(1) \cdot p(1) > K + C(v(2)),$$

which is expression (12) of the proposition.

By similar reasoning, an equilibrium with an arbitrary number, $l < n$, of investing firms does not exist if an additional firm has an incentive to invest, or if

$$\frac{n-l}{n} \cdot v(l) \cdot p(l) + \frac{l-1}{n} \cdot v(l-1) \cdot p(l-1) > K + C(v(l)),$$

which corresponds to the requirement in the proposition.

In short, a time-consistent, socially optimal equilibrium can be attained with marketable permits.

5. EXTENSIONS AND ROBUSTNESS

We have seen that tradeable permits can solve a hold-up problem. The model can be extended in several directions. First, we could solve for optimal emission taxes, denoted by $t(l)$, which, like the amount of permits, depend on the number of prepared firms when taxes are determined in Stage 2. Government sets a tax that induces prepared firms to reduce emissions to ex post efficient levels. Hence $t(l) = C'(v(l))$ for $l \geq 1$. So in addition to investment costs and costs of emission reduction, prepared firms must pay an emission tax. Because the sum of emission taxes and the costs of abatement are lower for the investing than for noninvesting firms, investment may still be profitable. However, it is evident that the hold-up problem may be less problematic or may be more easily solved with a system of marketable permits because prepared firms gain from selling permits instead of paying taxes.

For simplicity of presentation, we assumed that firms that do not invest in abatement equipment can reduce their emissions only by reducing output. Suppose instead that unprepared firms can also reduce their emissions, albeit at a higher marginal cost, denoted by $C_{un}(v)$, than prepared firms. Then the previous analysis still holds as long as $C'_{un}(0)$ is greater than marginal costs of prepared firms at the socially optimal emission reduction level $v(l)$. If this is not the case, social optimality also requires noninvesting to abate to some extent. Because the number of permits unprepared firms need to buy declines, the advantage of marketable permits in solving the hold-up problem declines. However, the hold-up problem itself is less serious in this case, because the regulator can induce noninvesting firms to reduce emissions.

Firms may be able to invest in abatement equipment ex post, after the regulator has issued permits. In such a model, with multiple time periods, firms could decide on investment, in each period allowing them to reduce emissions in the next period. If the life of permits covers more than one period, an equilibrium is more likely to have no firms investing. An unprepared firm could invest ex post to save the expenses for permits if other firms have invested. This would reduce the incentives for firms to invest upfront because prices of permits would fall. A detailed analysis of the dynamic interaction of investment decisions and credibility in permit markets is, however, needed to obtain a complete picture of investment incentives.[13] Moreover, in such a framework we could allow firms to vary the investment levels continuously between zero and an upper bound. This could induce firms to overinvest, with the aim of gaining from the sale of permits. On the other hand, the penalties from less investment than socially optimal is punished less by the need to buy the remaining permits Whether we obtain socially optimal investment levels or underinvestment or overinvestment depends crucially on the investment cost function and the cost function for emission reductions. A complete analysis is left for future research (see also Gersbach [3]).

6. DISCUSSION AND CONCLUSION

The model leads to several conclusions.

Under some conditions, marketable permits can lead to the socially efficient solution if the regulator can commit to open the market for permits after firms have invested. Marketable permits can be effective even if, in equilibrium, no permit is traded and its price is low. That is, the advantages of permits lie not only in allowing emissions to be reduced by the firms that can do it most cheaply.

Market structure can be important for the effectiveness of regulations. In particular, whereas a monopolist may be able to resist regulation, firms in a market with two or more noncolluding firms can be induced to invest.

Negotiations about new environmental regulations with industry associations can exacerbate the hold-up problem. As observed in the German automotive industry, industry associations can argue that introducing pollution reduction is too costly. Negotiations with industry associations are often viewed as promoting consensus about feasible technology improvements. Because, however, firms benefit if they can commit not invest, the industry association may promote collusion to avoid investment.

[13] See also Biglaiser, Horowitz, and Quiggin [2]

The market solution may apply to other hold-up problems. For instance, the regulator may design a cross-licensing market for patent rights for an innovation that lowers the cost of compliance with the regulation. Equilibria with such a four-stage mechanism are characterized by at least one firm innovating: for if no other firms invest, the profits in the license market are high.

We say that taxes are less suitable to solve the hold-up problem. In particular, emission taxes can yield equilibria with fewer (and in particular with no) firms investing. Although emission taxes would be lower for the complying firm than for noninvesting firms, the investing firms only save part of the emission tax, but it is not compensated for its investment as it would occur under permit markets. When government can regulate by issuing permits, the equilibrium (given the same cost conditions) may have investment and regulation [for details see Gersbach [3]].[14]

Consider, moreover, the political pressures on government if some firms did invest. Under Pigovian taxes no firm profits from the imposition of an emissions tax. Under permits, those firms that did invest may profit from regulation of emissions, because the regulation allows prepared firms to earn revenue by selling permits. Of course, unprepared firms lose from the imposition of emission regulations. But they also lose under emissions taxes.

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