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Have Incentive Based Policies Been Oversold?

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Advocates of regulatory reform often assert that incentive based (IB) environmental policies will reduce costs of compliance to one-tenth (or less) what would be experienced with conventional regulatory schemes (e.g. so called command and control (CAC) measures).[1] The early evidence marshaled to support these judgments is taken from Tietenberg [1985]. His summary compared the costs estimated from models describing different hypothesized CAC schemes to least cost policies.[2] More recently, prices from the sulfur dioxide permit trading program have been compared with the initial estimates of the incremental costs of control to offer similarly dramatic conclusions.[3] Unfortunately, neither type of comparison permits a judgment on what can be expected from using incentive based policies under an array of different actual conditions.

This paper uses an evaluation of the "new frontier" of IB policies—non-point source pollution—to consider how these policies should be evaluated and, in the process, to develop conceptual and empirical evidence supporting four specific observations about the cost savings attributed to IB policies. First, as already suggested, there is little consistent evidence in the literature on the actual savings in compliance costs from IB strategies. Most of what we think we know is derived from models. Second, none of the summaries of these IB/CAC cost comparisons

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[1] These judgments were clearly a part of the EPA/DOE essential evaluation of the costs of meeting global restrictions on CO_2. The *1998 Economic Report of the President* suggested that ". . .even in comparison with a system with full domestic trading of emission permits, international trading could substantially lower costs. Some models predict that the incremental cost of reducing CO_2 emission may be as little as one-seventh of the cost of reductions from domestic trading alone" (p. 170, emphasis added). EPA estimates the annual cost saving from the SO_2 program to be one billion dollars (Stavins [forthcoming]).

[2] Tietenberg [1985] (pp. 68-69) reports ratios of CAC to IB for the emission permit trading systems and models involving air pollutants ranging from .42 to 11.10. Schwabe [1996] (pp. 58-59) considered the sources of differences in costs with waterborne pollutants that also varied. However, in this case the definition of costs as well as the structure of the model was considered as sources for the difference in results (in addition to the likely differences in actual circumstances for the areas being modeled).

[3] The 1998 Council of Economic Adviser's Report is one such example, noting that: "One measure of the decline in cost relative to expectations is the trend in emission permit prices. Currently, at approximately $100 per ton of SO_2, permit prices are well below earlier estimates of around $250 to $400 per ton. These prices reflect the short-

has acknowledged the differences in the definition of costs and in the specification of the outputs produced by the activities represented in the models used for these comparisons. By assuming compliance costs are separable from production activities, these ratios can make small differences in the total costs of production accompanying the use of IB versus CAC appear dramatic. Third, none of the actual or proposed incentive based policies mimics a least cost solution. Indeed, the two extremes being compared (i.e., CAC versus IB) rarely exist in practice. Most policies are mixtures of the two. Thus, what are designated as IB policies in the "real world" simply place more weight on the incentive components of regulatory policy. Fourth, and finally, evaluating any of these policies requires including more detail about the features of the production and control technologies and of the environmental media that receives residuals. The ability to measure adequately the differences in compliance costs from alternative policies lies in authentically modeling the heterogeneity in incremental control costs induced through these details.

I. Modeling Incentive Based Policies

To illustrate the importance of nonseparability and technical detail (i.e. of production processes and environmental media), consider modifications to a model used to describe how the initial distribution of emission permits affects the performance of market based environmental policy.[4] Q_i designates firm i's emissions, $C_i(Q_i)$ the cost of controlling emissions, Q_1^0 the initial allocation of permits to firm one (the firm selected to illustrate the effects of an initial allocation) and L the total amount of emissions permitted from N firms (or plants). If firm one seeks to

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run marginal cost of reducing SO_2" (p. 160). For more detailed analyses of the reasons for lower emission permit prices see Ellerman and Montero [1996].

[4] The model outlined here is adapted from Hahn's [1984] analysis of the effects of different initial permit distributions.

minimize the cost of control, recognizing it can buy or sell permits at *P*, then we can consider whether firm one will equate its incremental control costs to the market price by evaluating the first order conditions to the minimization problem in equation (1):

$$Min\ C(Q_1) + P \bullet (Q_1 - Q_1^0) \qquad (1)$$

subject to: $Q_1 = L + \sum_{J=2}^{N} C_{Q_j}^{-1}(P)$

$C_{Q_j}^{-1}(P)$ recognizes that each of the other firm's response to a change in the price of permits will depend on its incremental emission control cost. To determine how demand or supply will respond to a change in *P* we solve $P = -C_{Q_j}(Q_j)$ for Q_j. Note that given our definitions, $C_{Q_j} < 0$. Firm one recognizes these responses in deciding its level of emission control. Substituting for Q_1 and considering the price that would minimize firm one's costs we have equation (2):

$$(C_{Q_1} + P)\sum_{J=2}^{N} C_{Q_j Q_j}^{-1} + (L + \sum_{J=2}^{N} C_{Q_j}^{-1}(P) - Q_1^0) = 0 \qquad (2)$$

As a rule we would expect the second term to be zero. The first term simply tells us that firm one will adjust its control activities, recognizing both its initial allocation (and the effect of its decisions on the permit price), until $P = -C_{Q_1}$.

This finding is hardly surprising. However, consider the way these policies are actually implemented. In equation (1) the opportunity cost of holding the initial amount of permitted emissions allocated to the firm is the market price. This need not be the case. For example, state utility commissions may not permit investor owned utilities to sell off all their permits without permission. Often this requirement for prior review amounts to restricted sales because commissioners do not accept the firm's judgment about future needs.[5] In some cases, firms are segmented into groups that cannot freely trade. In this situation the largest group (in terms of emissions) may set the price. If the firm being considered is not be part of that group, then its permit sales may face a different price. This alternative price would then become the relevant opportunity cost and overall responses become irrelevant for the firm's decisions.

Modifications to (1) to more accurately reflect the details of the problem serve to accentuate how these departures from the simple textbook story can matter. Suppose instead of emissions, the focus of the policy was environmental quality, E, and that non-treatment alternatives (or equivalently nonseparabilities in the compliance / production activities) are important to understanding abatement costs. Under these conditions the emission permit market would be measured in units related to E. Permit prices (now designated P^*) would also be expressed in units of environmental quality. The assumption of nonseparabilities in control and production implies that the abatement costs will now depend on emissions controlled and on market outputs, q. Equation (3) now corresponds to the condition defined in the simpler framework by (2). This equation makes it clear that the first and second order properties of the abatement technology and environmental media can be important depending on the specific design of the IB policy. The sum of changes in incremental control costs across firms influences firm one's behavior when incentive based policies induce firms to respond to an opportunity cost that is different from the overall market price for permits.[6]

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[5] See Dudek and Goffman [1992] and Solomon and Rose [1992] for alternative discussions of how utility commissions can enhance the incentives for private firms to participate in SO_2 trading.

[6] This formulation is itself simplified because we have ignored how other firms' emissions influence the impact of each firm's emissions on environmental quality. Such a framework would imply that $E_i = h(Q_i)$ would be specified as a function of the emissions from other firms. This would imply a much more complex scheme to account for the marginal effect of each firm. See Schwabe [1998] for a discussion in the case of two firms.

$$(C_{Q_1} h_{E_1}^{-1} + P^*) \sum_{J=2}^{N} [C_{Q_j Q_j} (h_{E_j}^{-1})^2 + C_{Q_j} \cdot h_{E_j E_j}^{-1}]^{-1} + (\ell + \sum_{J=2}^{N} h_{E_j} (\frac{P^*}{C_{Q_j}}) - h(Q_1^0)) = 0 \qquad (3)$$

where ℓ measures the total permitted emissions in quality units.

This first order condition can be used to make a variety of points. The most important of them is that the design of the IB system directly affects the link between permit price and incremental control costs. To the extent the additional terms in (3) do not "drop out" of the equation, then we can expect the policy would create ambiguous incentives for firms to equate their marginal costs (appropriately measured) to the permit price. This outcome also implies incremental costs will not be equalized across the sources of emissions, and, as a result, the overall level of control realized under the IB policy will not be the same as the least cost "solution." Thus, there is no reason to believe such an IB policy would actually dominate all CAC policies. The factors influencing the differences depend on the details of each problem.

The summation of second order properties of both abatement cost and environmental media in the first term in (3) becomes important when there is some reason to believe the second term in (3) is not zero. The design of the IB system makes the details of the cost and quality response to emissions across firms especially important. Nonseparability in abatement control is important even when the second term drops out because C_{Q_1} can be expected to be a function of the vector of marketed outputs (*q*) each firm produces.[7]

All too frequently analysts are tempted to ignore these details and describe the whole issue as simply a question of the units used to measure the permits. We can see how this misconception

[7] This point was an indirect insight from the initial large scale process analysis models developed by Russell [1973] and Russell and Vaughan [1976] as part of their early efforts to estimate the residuals generated by different production activities. In the case of the non-point sources of nutrients in the Neuse River model, the nutrient control practices of controlled drainage and conservation tillage have direct effects on output. In some cases even vegetative filter strips that require removing land from cultivation could be found to have non-separable effects.

arises by assuming the second term in (3) is zero, then the summation drops out (provided it is not zero).[8] A comparison of the results from each model in equations (4a) and (4b) illustrates how it might be possible to interpret emission based versus ambient quality based permits as simply a question of the units used to measure each permit.

$$P = -C_{Q_1} \tag{4a}$$

$$P^* = -C_{Q_1} \cdot h_{E_1}^{-1} \tag{4b}$$

To answer whether it is important we must consider real world examples such as nutrient control for the Neuse River Basin in North Carolina.

II. The Quantitative Importance of Incentive Based Environmental Policies

The preceding argument established that on conceptual grounds, we should expect that IB policies ability to enhance resource allocation depends on the design of the policy. Of course, all evaluations of these policies are done within some type of model that will embody a level of detail. Indeed, how well these estimates correspond to the actual gains realized in practice depend on how accurately each aspect of the model's representation corresponds with real world conditions. To illustrate these arguments we use a large, nutrient balance model that includes point and non-point sources of nutrient loadings in the Neuse River. This basin, with over 3,000 stream miles, has been a catalyst for debates over nutrient control in North Carolina. Excess nitrogen loadings in this and other rivers have been argued to be among the principle contributing factors responsible for the declines in coastal and estuarine water quality and for fish kills during summer months.

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[8] This condition implies that there must be some heterogeneity in cost or environmental impact.

The model includes a detailed description of non-point source pollution from cropping activities in the twelve counties of the river basin. The three crops accounting for over 70% of planted acreage in the basin (i.e. corn, cotton, and soybeans) are included along with eighteen wastewater treatment plants along the river.[9] The modeling of agricultural sources of nitrogen consider the nutrients entering and leaving production activities, pre-control transport from the fields, control technologies related to the field preparation and characteristics, post control field transport, and stream transport. A variety of treatment options are incorporated in the modules of the model that describe each treatment plant. Their location along the river is recognized through differentiated stream transport effects from their loadings in relation to the water quality at the estuary. Nutrient effects from all sources are measured at the estuary (Pamlico Sound).

The 723 column model was developed in a cost minimizing, linear programming format that permits comparison of the effects of specific modeling decisions (e.g. treatment of heterogeneity in soil conditions, stream transport, and output reallocations within the river basin) as well as policy design. The non-point source modules permit changes in the allocation of output across counties as well as in the use of nutrient control technologies, such as controlled drainage and conservation tillage, that have implications for both the production costs (and are therefore not separable) and for the nitrogen loadings from these sources.

Two comparisons of model runs reinforce the arguments from our analysis of IB policies. The top half of table 1 compares the role of model heterogeneity for evaluations of the gain from IB over CAC policy controlling only the non-point sources of nitrogen. To facilitate comparison with more the detailed variants of the model we compare the ratio of CAC to IB costs for a thirty

[9] In the baseline solution, non-point source loadings account for 80% of the estimated five million pounds of nitrogen. With a "pure" incentive based system, constrained to meet a 30% reduction in loadings, non-point source would account for a larger fraction of total loadings, about 85% of the policy target.

percent reduction in nitrogen loadings. These ratios vary from 1.33 to 1.09 depending on the treatment of production conditions, stream transport, and the potential for reallocating crop production across the counties within the river basin. The first row in part B of the table considers the same ratio for the full model (and thus a larger base level of nitrogen loadings). The full model includes the wastewater treatment plants as well as nitrogen loadings from hog farms that are assumed incapable of reducing nitrogen loadings. This is important because it increases the baseline loadings and the effort remaining sources must undertake to realize the 30% reduction. In this scheme the least cost solution would save 33% of the costs required under a CAC system.

The remainder of part B of the table compares the efficiency gains from two policies proposed to control nutrients entering the Neuse. The first attempts to characterize North Carolina's Division of Water Quality 1996 plan. This plan has three primary components:

- a 30% reduction in nitrogen loadings measured at the estuary from point sources as a group, (i.e. wastewater treatment plants) that are members of a "Lower Neuse Basin Association" (i.e. allowed to trade permits to emit nitrogen).
- a nitrogen concentration limit that cannot exceed 6mg/l from seven other wastewater treatment plants.
- a vegetative buffer strip of at least 50 feet on both sides of all perennial and intermittent streams in the river basin.

Table 1: The Costs of CAC to IB Policies Under Alternative Model and Policy Designs

Model/Policy Scenario	CAC/IB Cost Ratio	Least Cost[a] (1994 dollars)
A. Non-Point Source Modeling Variations[b]		
(a) Basin-Wide Reallocation of Agricultural Output	1.20	5,520
(b) Constrain County to Meet Constant Agricultural Output	1.11	4,658
(c) Constrain County to Meet Constant Output with Homogeneous Stream Transport	1.09	4,732
(d) Constrain County to Meet Constant Output with Homogeneous Soil	1.33	3,100
B. Policy Design Variations		
(a) Pure CAC to IB with full model	1.33	6,080
(b) 1996 Neuse River Plan	1.01	9,077
(c) Mixed System	1.22	7,199

[a] These costs are measured in thousands of dollars and include compliance and production costs for a fixed total production level of corn, cotton and soybeans from the counties in the Neuse River basin. Loadings from hog farms in the basin were treated as background sources of nitrogen and held unchanged across the policy options with the full model. See Schwabe [1996] for a detailed description of the models.
[b] Costs do not include the annual compliance costs for waste water treatment plants.

To evaluate how requiring a specific control technology (e.g. the vegetative filter strip) can influence costs we also impose the 30% reduction on all non-point sources with this restriction and then consider the same reduction by county, but allow flexibility in the control option they use and allow full permit trading for the eighteen wastewater treatment plants. This is designated the mixed policy in part B of the table. In the restricted case the estimated compliance cost savings due to the 1996 Neuse Plan (using the full model) would be negligible, about one percent. The small savings can be attributed to the limitations on trading arising because of the restrictions on the control options used by non-point sources. If we consider a different alternative that recognizes the difficulties of implementing a permit trading system with non-point sources and therefore impose a flexible CAC system for them along with full incentive based trading for point sources, then we bring the cost savings close to a pure cost minimizing system, with a CAC to IB cost ratio of 1.22 versus 1.33 for the least cost case. Thus, the details of the design of both the modeling and the policy matter in evaluating the estimated performance of incentive based policies.

III. Implications

There are at least two reasons for being skeptical about the size of the cost advantages attributed to incentive based environmental policies. First, the extent of the cost differential is derived from estimates in models that routinely treat environmental compliance costs as separable from production costs. Few actual processes would be consistent with this restriction. Second, and equally important, least cost approaches to realize a pre-defined level of environmental quality do not mimic real world IB policies. Rather, they represent compromises that are best treated as mixtures of IB and CAC approaches.

When compliance and production costs are not separable, large savings in a small share of total costs may not be sufficiently important static advantages for individual firms.[10] Nonetheless, they can be important in quantitative terms at an aggregate level if the sectors involved include heterogeneous firms with quite different compliance conditions. Our analysis of the Neuse river basin suggests that measured cost savings can differ by a factor of almost four solely as a result of modeling structure. When the framework is expanded to include point sources and incentive based policies are modeled to correspond to the ways they are implemented in practice, then the differences can be greater. CAC and the "actual IB" policy are indistinguishable in total costs, but the distribution of costs across point and non-point is quite different.[11]

These arguments are not simply an academic reality check to the current policy enthusiasm for incentives. Even with the limited evidence from actual experience, incentive based policies can reduce compliance costs. However, these reductions require that policies be designed to

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[10]As we argued throughout, the cost difference between CAC and IB varies with model and policy design. The table below compares the effects considering the ratio of CAC to IB based on total costs versus control costs for models with output constrained to be constant in each county (designated County Constrained) versus basin wide reallocation (designated Basin Wide) for a 30% reduction in nitrogen loadings.

(CAC/IB)

	County Constrained		Basin Wide	
Policy	Total	Control	Total	Control
Pure IB	1.019	1.514	1.023	1.721
Separate IB's—Non-Point and Point	1.017	1.416	1.021	1.603
Non-point CAC and Point IB	1.012	1.219	1.013	1.303
Non-point IB and Point CAC	1.004	1.082	1.008	1.168

[11] The share of the costs imposed on non-point sources with the four plans are:

Plan	Share to non-point source
CAC	.694
IB	.644
1996 Neuse River Plan	.763
Mixed Plan	.888

See Schwabe [1996] for more details of the distribution by county.

assure the incentives are in fact provided and that there is flexibility in how those impacted by the incentive are able to respond to them. Deciding in advance that the "best" technology will be mandated for all and that all will face IB policies does little to assure there are effective incentives available.

Consider an example directly relevant to the case of non-point source pollution. Recent EPA proposals for dealing with non-point source pollution as part of reauthorization of the Clean Water Act call for mandating buffer strips along nearly three million miles of rivers with adjoining agricultural activities that are likely to contribute to nitrogen levels. These requirements are to be imposed together with incentive based policies for point and non-point sources of nutrients. Our analysis of the Neuse River Basin suggests the effectiveness of these vegetative filter strips depends on soil conditions. Buffer strips as a nutrient control technology are ineffective when the land involved consists of flat, sandy soil with a higher water table, where most nutrients leave in subsurface water flows. Introduction of incentives under these conditions may not be able to overcome or compensate for the needless expenditures associated with the mandated buffer strips.

Overall, then, judging the efficiency of mixed systems comprised of CAC and IB components requires models with sufficient detail to capture both the technical heterogeneity giving rise to differences in compliance costs and the environmental conditions that influence the resulting quality levels realized with different spatial distributions of emission controls.

REFERENCES

Council of Economic Advisers. 1998. *Economic Report of the President* (Washington, D.C.: U.S. Government Printing Office).

Dudek, Daniel J. and Joseph Goffman. 1992. "Jump Starting the Allowance Market," *The Electricity Journal*, 5 (June): 12-17.

Ellerman, A. Denny and Juan P. Montero. 1996. "Why Are the Allowance Prices so Low? An Analysis of the SO_2 Emission Trading Program," (Cambridge: Center for Energy and Environmental Policy, Massachusetts Institute of Technology).

Foster, Vivien and Robert W. Hahn. 1995. "Designing More Efficient Markets: Lessons from Los Angeles Smog Control," *Journal of Law and Economics*, 38 (April): 19-48.

Hahn, Robert W. 1984. "Market Power and Trasferable Property Rights," *Quarterly Journal of Economics*, 99 (November): 753-766.

Russell, Clifford S. *Residuals Management in Industry: A Case Study of Petroleum Refining* (Baltimore: Johns Hopkins University, 1973).

Russell, Clifford S. and William J. Vaughan. *Steel Production: Processes, Products and Residuals* (Baltimore: Johns Hopkins University, 1976).

Schwabe, Kurt A. 1996. Source Heterogeneity, Resource Characteristics, and the Performance of Marketable Permits (unpublished Ph.D. thesis, North Carolina State University).

Schwabe, Kurt A. 1998. "The Effect of Output Specification and Heterogeneity in Modeling Non-point Source Pollution Regulations," unpublished working paper, Department of Economics, Ohio University (January).

Solomon, Barry D. and Kenneth Rose. 1992. "Emission Trading: Incentives—Not Pre-approved," *The Electricity Journal*, 5 (July): 58-68.

Stavins, Robert N. "What Can be Learned From the Grand Policy Experiment? Lessons from SO_2 Allowance Trading," *Journal of Economic Perspectives*, forthcoming.

Tietenberg, Thomas H. 1985. *Emission Trading: An Exercise in Reforming Pollution Policy* (Washington, D.C.: Resources for the Future).