Instrument Choice in Environmental Policy

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Introduction

The choice of pollution control instrument is a crucial environmental policy decision. With growing momentum for federal legislation to control greenhouse gases, interest among policy makers in the issue of instrument choice has reached a fever pitch. The toolkit of environmental instruments is extensive, and includes emissions taxes, tradable emissions allowances ("cap-and-trade"), subsidies for emissions reductions, performance standards, mandates for the adoption of specific existing technologies, and subsidies for research toward new, "clean" technologies. How to choose among the alternatives?

The choice is inherently difficult because competing evaluation criteria apply. Economists have tended to focus on the criteria of economic efficiency (a policy's aggregate net benefits) and its close relative, cost-effectiveness. Other important criteria are the distribution of benefits or costs (across income groups, ethnic groups, regions, generations, etc.) and the ability to address uncertainties. Some analysts would also include political feasibility as a criterion.

Evaluating the impacts along any one of these dimensions is hard enough. For example, judging alternative instruments in terms of cost-effectiveness alone is difficult, since a comprehensive assessment of cost would include not only the negative impacts on the regulated entity but also monitoring and enforcement costs and general equilibrium impacts outside the sector targeted for regulation. Considering several dimensions is harder still. Beyond the theoretical and empirical challenges involved, there is a sobering conceptual reality: the absence of an objective procedure for deciding how much weight to give to the competing normative criteria. As a result, selecting the "best" instrument involves art as well as science.

A basic tenet in elementary textbooks is the "Pigouvian" principle that pollution should be priced at marginal external cost. This principle usually suggests that emissions taxes are superior to alternative instruments. While the Pigouvian insight remains highly valuable, research conducted over the past few decades indicates that it is not always sufficient or reliable because of information problems, institutional constraints, technology spillovers,

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and fiscal interactions. A more sophisticated set of considerations is required, which at times will justify using instruments other than emissions taxes.

This essay attempts to pull together some key findings in the recent literature and distill lessons for policy makers. A full treatment of the major issues would occupy an entire volume, perhaps several. Our goal is therefore to sketch out key strengths and weaknesses of alternative environmental policy instruments and refer the reader to relevant studies for the details.[1]

A number of issues are beyond the scope of this article. First, we focus exclusively on mandatory policies; voluntary programs as well as information disclosure programs, such as the Toxic Release Inventory and Energy Star, are beyond our scope (for details see Tietenberg and Wheeler 2001 and Lyon and Maxwell 2002). In addition, we concentrate on domestic policy choice, giving relatively little attention to strictly international considerations relevant to instrument choice or policy design (for details see Aldy and Stavins 2007 and Nordhaus 2007). Finally, our approach is largely normative: while we offer a few comments about why certain instruments tend to have greater political success than others, we do not provide an in-depth analysis of the (positive) political economy of environmental regulation (on this, see Keohane, Revesz, and Stavins 1998).

Several general themes emerge from the discussion, including:

- No single instrument is clearly superior along all the dimensions relevant to policy choice; even the ranking along a single dimension often depends on the circumstances involved.
- Significant trade-offs arise in the choice of instrument. In particular, assuring a reasonable degree of fairness in the distribution of impacts, or ensuring political feasibility, often will require a sacrifice of cost-effectiveness.
- It is sometimes desirable to design hybrid instruments that combine features of various instruments in their "pure" form.
- For many pollution problems, more than one market failure may be involved, which may justify (on efficiency grounds, at least) employing more than one instrument.
- Potential interactions among environmental policy instruments are a matter of concern, as are possible adverse interactions between policies simultaneously pursued by separate jurisdictions.

The rest of the article is organized as follows. The next section investigates the cost-effectiveness of alternative emissions control instruments using a relatively narrow, traditional notion of cost, while the third section considers broader cost dimensions. Section 4 explores other considerations relevant to the choice among emissions control instruments. Although much of our focus is on policies aimed at reducing emissions, an important role of decision makers is to consider policies that directly promote the invention or deployment of new technologies. Therefore, in Section 5 we briefly discuss the rationale for supplementing emissions control policies with technology-focused policies. Section 6 considers some further environmental and institutional issues that complicate the choice of instrument. The final section summarizes our conclusions about instrument choice and

[1]For other reviews of the literature see Hepburn (2006) and Tietenberg (2006).

identifies some of the challenges faced by environmental economists working in this area today.

Cost-Effectiveness of Alternative Emissions Control Instruments

We start our discussion with a comparison of the costs of achieving given emissions reductions using different instruments.[2] For now we apply a narrow interpretation of cost, one that encompasses only compliance costs within the firms or industries targeted for regulation.

Minimizing the cost of reducing pollution by a given targeted amount requires equating marginal abatement costs across all potential options and agents for emissions reduction, including:

- *the various abatement channels* available to an individual firm or facility: namely, switching to cleaner inputs or fuels, installing abatement capital (e.g., postcombustion scrubbers), and reducing the overall scale of production.
- *firms or facilities within a production sector*—which may face very different costs of abatement and existing emissions intensities.
- *production sectors*, such as manufacturing and power generation.
- *households and firms*, where household options might include reducing automobile use or purchasing more energy-efficient appliances or vehicles.

In theory, these conditions are satisfied when all economic actors face a common price, at the margin, for their contributions to emissions (Baumol and Oates 1971). In such circumstances, every firm in every (emissions-producing) sector has an incentive to exploit all of its abatement opportunities until the marginal cost of reducing emissions equals the emissions price, thereby assuring that the first three conditions listed above are satisfied. Moreover, the cost of emissions control and the price paid for remaining emissions will be passed forward into the prices of final goods and services. Consequently, consumers will face prices reflecting the emissions associated with the production of the goods they buy or the services they use. Thus, in keeping with the fourth condition above, their consumption choices will account for their contributions to emissions.[3] Because all agents will be charged the same unit price for their direct or indirect contributions to emissions, the marginal costs of emissions reductions of all agents will be equal.

Maximizing cost-effectiveness requires that all agents face the same price on emissions. The stronger condition of maximizing the efficiency gains from policy intervention implies a particular level for this price: namely, the one that equates the marginal benefits and costs of emissions reductions.

[2]Although we treat the emissions-reduction target as given and compare the costs of meeting that target with different instruments, in reality the target itself may be endogenous to the choice of instrument, as the selected target may be revised in response to changes in perceptions about the magnitude of abatement costs.

[3]This holds even when competitive supply curves are upward sloping and firms cannot pass through all the costs of regulation.

In reality, environmental regulations are rarely comprehensive enough to apply a given emissions price to all economic sectors or agents. For example, the European Union's Emissions Trading Scheme (ETS) currently covers sectors responsible for only about half of the EU's CO_2 emissions. Far more frequently the goal is to maximize cost-effectiveness within a targeted sector or set of industries. Imposing a common emissions price on all agents within the targeted sector or group of industries will minimize costs (narrowly defined) within that group, but generally will not lower costs as much as a more comprehensive program can.

Having offered this brief introduction, we now compare instruments whose main purpose is curbing emissions or effluent (as opposed to directly promoting the invention or deployment of new technologies). These include both *incentive-based instruments* and *direct regulatory instruments* (sometimes called "command-and-control" instruments).[4] The attributes and advantages of each instrument are summarized in Table 1 and discussed in turn below.

Incentive-Based Instruments

Incentive-based instruments include emissions taxes, tradable emissions allowances, subsidies for pollution abatement, and taxes on inputs or goods associated with emissions (e.g., a gasoline tax).

Emissions Taxes and Tradable Allowance Systems

What specific instruments might establish a common emissions price? Clearly an emissions tax is one. A system of tradable emissions allowances (or "cap-and-trade") is another, since it also imposes a single emissions price on all covered sources—that is, all firms or facilities must justify their emissions by submitting allowances. This holds whether the allowances are initially distributed through an auction or by free allocation. In either case, an additional unit of emissions implies a cost equal to the allowance price, since it compels the agent either to purchase one extra allowance or to sell one fewer (and forgo revenue). As under the emissions tax, both the costs of abatement and the emissions price are reflected in higher prices of consumer products.

Subsidies for Pollution Abatement

Another potential emissions pricing instrument is a subsidy for pollution abatement, where firms are rewarded for every unit of emissions that they reduce below some baseline level. At the margin, this instrument provides the same incentives as emission taxes or cap-and-trade, since every additional unit of emissions implies a cost to the firm in forgone subsidy receipts. Thus, these subsidies can bring about the same choices for input intensities and end-of-pipe treatment as other emissions pricing policies. However, in practice such subsidies are less cost-effective than emissions taxes or tradable allowances. Since they lower firms' average costs, they provide the wrong incentives regarding the level of output, which leads to excess

[4]We prefer to use "direct regulatory instruments" rather than "command-and-control" instruments, which has a somewhat negative connotation.

Table 1 Attributes of alternative emissions control instruments

	(1)	(2)	(3)	(4)	(5)
	Promotion of lowest-cost combination of input choice, end-of-pipe treatment, and output reduction	Equalizing of marginal emissions reduction costs across heterogeneous firms	Minimization of general equilibrium costs from interactions with broader tax system	Political feasibility (low share of regulatory burden falling on emitters)	Fairness across income groups (limiting disproportionate burden on low-income households)
Emissions control policies					
Emissions tax (revenue-neutral)	*	*	*		*
Subsidy to emissions abatement		*			
Tax on goods associated with emissions		*	*		
Tradable emissions allowances					
Auctioned (revenue-neutral)	*	*	*		*
Freely allocated	*	*		*	
Mandated abatement technology				*	*
(Non-tradable) performance standard				*	*

Notes

1. The asterisk indicates that a given instrument has an advantage along the dimension in question. It does not mean that other instruments have no impact along that dimension.
2. Other potentially important considerations excluded from the table are:
   (a) Ease of monitoring and enforcement;
   (b) Ability to maximize efficiency gains under uncertainty; and
   (c) Ease of policy adjustment (in terms of stringency, scope, etc.) in face of new information.

These dimensions are not included as column headings because the relative attractiveness of instruments along these dimensions depends critically on the particular circumstances involved.

entry.[5] As a result, to accomplish the same target emissions reductions as under the other two policies, regulators would need to make the marginal price of emissions (the subsidy rate) higher than under the other policies, leading to too much abatement from input substitution or end-of-pipe treatment, and too little from reduced output. This implies higher aggregate costs of achieving a given emissions target.

Taxes on Inputs or Goods Associated with Emissions

Still another pricing instrument is a tax on an input, produced goods, or service associated with emissions. Taxes on gasoline, electricity, or air travel are examples. These taxes may be an attractive option when it is difficult to monitor emissions directly (see below). However, because these taxes do not focus sharply on the externality, they do not engage all of the pollution reduction channels described above, implying a loss of cost-effectiveness. For example, a tax on electricity lowers emissions by raising electricity prices, which lowers equilibrium demand and output; but it provides no incentives for clean fuel substitution in power generation or for the adoption of electrostatic emissions scrubbers (a form of postproduction or "end-of-pipe" treatment). Similarly, although a gasoline tax might encourage motorists to drive hybrid or more fuel-efficient vehicles, it provides no incentives for them to drive cars that burn gasoline more cleanly, or for refiners to change the refinery mix to produce a motor fuel that generates less pollution when combusted.

Direct Regulatory Instruments

Compared with emissions taxes and tradable emissions allowances, direct regulations such as technology mandates and performance standards are at a disadvantage in meeting the conditions for cost-minimization. The disadvantages reflect information problems faced by regulators as well as limitations in the ability of these instruments to optimally engage the various channels for emissions reductions.

Technology Mandates

Consider first the impact of a technology mandate—a specific requirement regarding the production process. The mandate may require, for example, that firms install equipment that implies a particular production method. Given the heterogeneity among firms, it is extremely unlikely that a regulator would have enough information to set mandates that maximize cost-effectiveness—i.e., that cause marginal costs of abatement (through input-substitution and end-of-pipe treatment) to be equated across firms. If a single mandate is applied to all firms, cost-effectiveness will be undermined to the extent that firms face different costs for meeting it (Newell and Stavins 2003).[6]

In addition, the technology mandate does not optimally engage all of the major pollution reduction channels. A technology mandate for end-of-pipe treatment generates no incentive

[5]It is theoretically possible to design a subsidy program that does not lead to excess entry. However, such programs are very difficult to achieve in practice. See Baumol and Oates (1988) for a discussion.
[6]For example, it may be a lot less costly for firms that are currently upgrading or constructing new plants to incorporate a new abatement technology than for firms that must retrofit older plants that are not readily compatible with the newly mandated technology.

to change the production mix towards cleaner inputs, while a mandate stipulating a particular input mix provides no incentive for end-of-pipe treatment. Both types of mandate fail to equate the marginal costs across the different options for reducing emissions per unit of output.

Moreover, these policies do not optimally utilize the output-reduction channel. Although the price of the firm's output will reflect the variable costs of maintaining the new technology, it will not reflect the cost of the *remaining* pollution associated with each unit of output. This implies that the output price will be lower than in the case of emissions pricing, where the output price will reflect both the variable costs from the new technology *and* (since firms must pay for their remaining pollution) the price attached to the pollution associated with each unit of output. Therefore technology mandates do not cause firms to reduce pollution sufficiently through reductions in the scale of output. Thus, in order to achieve the overall emissions-reduction target, the regulator would have to require firms to press further on the input-substitution and end-of-pipe channels than would be necessary under emissions-pricing instruments. The lower per-unit private cost and lower output prices might seem to give the technology mandate an advantage. However, because the scale of output is excessive and the other channels are "overexploited," the *aggregate* cost of achieving the emissions-reduction target—private cost per unit of output times aggregate output—is higher under this policy instrument than under emissions pricing (Spulber 1985; Goulder et al. 1999).

Performance Standards

While technology mandates impose requirements directly on the production process, performance standards require that a firm's *output* meet certain conditions. Examples include maximum emission rates per kilowatt-hour of electricity, energy efficiency standards for buildings or household appliances, and fuel-economy requirements for new cars.[7]

Rather than dictate the specific technique for reducing pollution (or improving energy efficiency), performance standards grant firms flexibility in choosing how to meet the standard. For example, power plants can satisfy maximum allowable emission rates through various combinations of fuel-switching and postcombustion scrubbing, and they can meet renewable portfolio standards by relying more on wind, solar, hydro, and possibly nuclear generation. Auto manufacturers can improve fuel-economy through their chosen combinations of reducing vehicle size, using lighter materials, changing car-body design, and advanced engine technologies. Because they offer greater flexibility, performance standards generally are more cost-effective than specific technology mandates.

As with technology mandates, performance standards fail to exploit optimally the output-reduction channel. Again, firms are not charged for their remaining emissions, which implies lower output prices than under a comparable emission pricing policy, and over-reliance on reducing the emissions intensity of production either through input-substitution or post-combustion ("end-of-pipe") treatment. For example, automobile fuel economy standards do not exploit emissions reductions through incentives to reduce vehicle miles of travel

[7] The performance standard described here is a requirement relating to a firm's output. Sometimes the term "performance standard" is used to refer to a constraint on inputs. Examples include minimum requirements for renewable fuels in power generation, and California's "low carbon fuel standard," which requires refiners to include a certain minimal percentage of "low carbon" fuel in the motor fuel they sell.

(or vehicle "output"). A gasoline tax, in contrast, does provide such incentives. Moreover, cost-effectiveness generally calls for different performance requirements among firms with differing production capabilities. Regulators generally lack the information required to tailor the standards to individual firms. On the other hand, this problem could be addressed by allowing some firms to undercomply, provided that they buy credits from other firms that go beyond the standard.

As shown in columns 1 and 2 of Table 1, the most cost-effective instruments under the narrow definition of "cost" are those that directly price the pollution externality: namely, emissions taxes and tradable emissions permits. Other price instruments are less cost-effective because they fail to exploit optimally all of the major channels for emissions reductions. Direct regulatory instruments also fail to engage optimally all of the major pollution reduction channels and, if nontradable, fail to equate the marginal costs of emissions reductions across heterogeneous firms.

Cost Comparisons

How important, in quantitative terms, are the differences in costs of the various instruments?

Tietenberg (2006) summarizes 14 simulation studies applied to different pollutants and regions. In all but two cases, abatement costs would be 40–95 percent lower under emissions taxes or tradable allowances than under technology mandates, (nontradable) performance standards, and other policies such as requirements that all sources reduce pollution in the same proportion. In the context of reducing gasoline, Austin and Dinan (2005) estimate that policy costs are around 65 percent lower under fuel taxes than more stringent fuel economy regulation (partly because regulation does not exploit opportunities for fuel savings through reduced driving). Palmer and Burtaw (2005), Fischer and Newell (2008), and Newell and Stavins (2003) estimate that, in the power sector, abatement costs would be about 50 percent lower under emissions pricing than under various performance standards.

In the circumstances considered by these studies, incentive-based policies have a large cost advantage. However, this may not be true in all cases. For example, the cost advantage will be modest if there is little heterogeneity among firms so that a single technology mandate can bring marginal abatement costs close to equality. Similarly, if incentive-based instruments only have a small effect on product prices, then the failure to optimally exploit the output reduction channel under direct regulatory approaches will not matter much in practice. And even if output reduction effects are important, the relative cost differences between emissions pricing and direct regulatory instruments may decline sharply as abatement approaches 100 percent (Goulder et al. 1999).

Broader Cost Considerations

This section expands the narrow notion of cost to include administrative costs and the cost impacts from fiscal interactions.

Administrative Costs

A broader notion of "cost" includes the costs of administering a pollution control program, particularly the costs of monitoring and enforcement (Heyes 2000, Stranlund, Chavez, and

Field 2002). In some instances, monitoring emissions is very costly or virtually infeasible. For example, it is extremely difficult, if not impossible, to keep track of "nonpoint" sources of water pollution caused by agricultural production. In circumstances where monitoring emissions is exceptionally costly, emissions pricing may lose its status as the most cost-effective option. Mandates for certain farm practices (like grassed water strips to limit chemical runoff, or lagoons and storage tanks to treat waste from large confined animal feeding operations) may be the most practical approach, as these can be monitored via satellite imagery or on-site inspections. And although an automobile's tailpipe emissions could be taxed using information from periodic odometer readings and emissions per mile data from vehicle inspection programs, it is administratively much easier to impose emission per-mile standards on automobile manufacturers. This alternative also avoids privacy concerns about government collection of data on household driving habits.

In some cases, high monitoring costs associated with emissions pricing can be avoided by employing a "two-part" regulatory instrument to approximate (and in some cases duplicate) the impact of emissions pricing. Eskeland and Devarajan (1995) show that a tax on automobile emissions can be closely approximated by combining a mandated emissions-control technology with a tax on gasoline. Intuitively, the technology mandate assures efficient substitution of the "inputs" (engine characteristics) used to produce transport, while the tax on gasoline helps employ the output-scale channel by raising the variable cost of transport (the car's output) to an efficient level. Similarly, if pay-by-the bag for household garbage is difficult to enforce in rural areas where it might encourage illegal dumping, an alternative might be to combine a packaging tax at the retail level with subsidies for household recycling (e.g., Fullerton and Wolverton 2000).[8]

Cost Impacts from Fiscal Interactions

The cost-ranking of emissions control policies is further complicated by general equilibrium impacts—in particular, interactions between these policies and the distortions in labor and capital markets created by the preexisting tax system. Fiscal interactions can substantially augment or reduce the advantages of incentive-based policies, depending on specific policy features. In fact, once fiscal interactions are taken into account, in some circumstances emissions-pricing policies are more costly than direct regulation.

A number of studies emphasize the idea that emissions mitigation policies affect tax distortions in factor markets, particularly those in the labor market created by income and payroll taxes (e.g., Goulder et al. 1997). The studies focus on two main connections with factor market distortions. First, under revenue-raising policies such as emissions taxes, fuel taxes, or cap-and-trade systems with auctioned allowances, the revenue can be used to finance reductions in existing factor taxes. This produces a first-order efficiency gain, equal to the increase in labor supply (or capital) times the difference between the gross- and net-of-tax factor price. Although the proportionate increase in economy-wide factor supplies may be very small, this beneficial "revenue-recycling effect" can be quite large in relative terms. A second effect works in the opposite direction. To the extent that the costs of environmental

[8]This combination has much in common with a deposit-refund system. For a discussion of such systems see Bennear and Stavins (2007).

policies are shifted forward to consumers (in the form of higher prices paid for refined fuels or energy-intensive goods and services), the consumer price level will rise, implying a reduction in real factor returns. This depresses factor supply, and the resulting efficiency loss, termed the "tax-interaction effect," raises the costs of environmental policies.

Prior studies indicate that under fairly neutral conditions the tax-interaction effect outweighs the revenue-recycling effect, though one can stipulate other conditions under which this is not the case.[9] To the extent that the tax-interaction effect dominates, environmental policies involve greater costs than if one ignored the fiscal interactions. For policies that raise no revenue (such as freely allocated emissions permits, performance standards or mandated technologies) or for policies that raise revenue but do not use them in socially productive ways, only the (costly) tax-interaction effect applies.

What do fiscal interactions imply for the choice among environmental policy instruments? First, they imply that the costs of emissions taxes and tradable emissions allowance systems will depend importantly on whether the system is designed to exploit the revenue-recycling effect. Emissions taxes with efficient recycling of the tax revenue have a cost-advantage over emissions taxes in which the revenues are returned as lump-sum transfers (e.g., rebate checks). Similarly, emissions allowance systems that raise revenue (through auctioning of allowances) and apply the revenue to finance tax cuts have a cost-advantage over emissions allowance systems in which the allowances are initially given out for free.

The cost-advantage can be substantial. For example, a \$20 per ton tax on CO_2 might raise annual revenues in the near term by roughly \$100 billion (the tax would have a modest impact on reducing current emissions, which are around 6 billion tons). If this tax were revenue-neutral, we would put the cost savings over an equivalent incentive-based policy that did not exploit the revenue-recycling effect at about \$30 billion a year. In fact, the decision about whether to auction or freely allocate emissions allowances—that is, whether or not to exploit the revenue-recycling effect—can determine whether an emissions allowance program, scaled to generate allowance prices that equal estimated marginal damages from emissions, produces overall efficiency gains (Parry et al. 1999). If it fails to exploit the revenue-recycling effect, firms' abatement costs, plus the tax-interaction effect, may exceed the benefits from reduced pollution.

Fiscal interactions also have important implications for the choice between emissions pricing instruments and other environmental policies. For a given pollution reduction, the tax-interaction effect for technology mandates and performance standards is often smaller than for emissions taxes and emission permits. This is because these policies can have a weaker impact on product prices, as they do not charge firms for their remaining emissions. In fact, at least in a homogeneous firm setting, the superiority on cost-effectiveness grounds of (freely allocated) permit systems over technology mandates and performance standards could be overturned because of the greater tax-interaction effect under the market-based policy (Goulder et al. 1999).[10]

In summary, consideration of fiscal interactions tends to favor (revenue-neutral) emissions taxes, other environmentally oriented taxes, and auctioned emissions allowance systems over

[9]See, for example, Bovenberg and Goulder (2002) and Parry (1998) for more detail.

[10]Abatement subsidies also generate interactions with the tax system. For a discussion of this case, see Parry (1998).

other policies when tax or auction revenues are used to finance cuts in existing distortionary taxes (Table 1, column 3).

Additional Considerations

This section discusses two other factors that are relevant to the choice among emissions control instruments: the ability of the instrument to address uncertainty, and the nature of its distributional impacts.

The Role of Uncertainty

Uncertainties are unavoidable: policymakers can never perfectly predict the outcome of environmental policies. This is relevant to instrument choice, since the choice of instrument affects both the type of uncertainty that emerges as well as the expected efficiency gains generated. Instruments also differ in their abilities to adjust to new information.

The Nature of Uncertainty under Different Instruments

Under emissions taxes, the price of emissions (the tax rate) is established at the outset. What is uncertain is the aggregate emissions quantity that will result after firms respond to the tax. In contrast, under pure emissions allowance systems, the aggregate emissions quantity is established at the outset by the number of allowances introduced into the market, while the emissions price is uncertain because it is determined by the market *ex ante*.

To reduce the price uncertainty under emissions allowance systems, some have proposed augmenting such systems with provisions for an allowance price ceiling or price floor. The idea of establishing a price ceiling has gained considerable attention in discussions of climate change policy. Here a cap-and-trade program is combined with a "safety valve" to enforce a pre-established ceiling price (Burtraw and Palmer 2006; Jacoby and Ellerman 2004; Pizer 2002). Under this policy, if the allowance price reaches the ceiling price, the regulator is authorized to sell whatever additional allowances must be introduced into the market to prevent allowance prices from rising further. Note that while the safety valve reduces price uncertainty, it introduces uncertainty about aggregate emissions. Similarly, it is possible to enforce a price floor by authorizing the regulator to purchase (withdraw from the market) allowances once the allowance price falls to the pre-established floor price.

Potential price volatility of allowance systems can also be reduced by allowing firms to bank permits for future compliance periods when current allowance prices are considered unusually low, and to run down previously banked permits or borrow permits when current allowance prices are considered unusually high.

Other instruments involve uncertainties about emissions prices, quantities, or both. Like an emissions tax, a tax on a goods associated with emissions (for example, a gasoline tax) leaves the quantity of emissions uncertain. Direct regulatory policies leave uncertain the amount to which aggregate emissions will be reduced, although they may indicate limits on emissions at the facility or firm level. Direct regulatory policies also involve uncertainties as to the effective price of emissions; that is, the shadow price of emissions or the marginal cost of abatement implied by the regulations.

Implications of Uncertainty for Expected Efficiency Gains

Maximizing the efficiency gains from pollution control requires that marginal damages from emissions (or marginal benefits from emissions reductions) equal society's (each firm's) marginal costs of emissions reductions. However, a regulator seeking to maximize efficiency gains will not have perfect information about marginal abatement costs, a reflection of the inability of the regulator to know each firm's current capabilities for input-substitution and end-of-pipe treatment. There is even more uncertainty as to future abatement costs, as these will depend on additional variables that are difficult to predict, such as fuel prices and the extent of technological change.

In the presence of abatement cost uncertainty, the choice of instrument affects the expected efficiency gains.[11] In a static context, the relative efficiency impact of a "price" policy such as an emissions tax compared to a "quantity" policy such as an aggregate emissions cap depends on the relative steepness of the aggregate marginal abatement cost curve and the marginal damage curve.[12] In a limiting case, where the marginal damage curve is perfectly elastic, expected net benefits are maximized under the emissions tax, with the tax rate set equal to the (constant) marginal damages. In this case the tax automatically equates marginal damages to marginal abatement costs, regardless of the actual location of the marginal abatement cost schedule. In contrast, if an aggregate emissions cap is employed, with the cap set to equate marginal damages with *expected* marginal abatement costs, abatement will be too high *ex post* if marginal abatement costs turn out to be greater than expected, and too low *ex post* if marginal abatement costs are lower than expected. The relative efficiency gains are reversed in the other limiting case: when marginal damages are perfectly inelastic, expected net benefits are maximized under the emissions cap. For intermediate cases, either the tax or the cap could offer higher net benefits, depending on whether the marginal damage curve is flatter or steeper than the marginal abatement cost curve (Weitzman 1974).

These results carry over to a dynamic setting, where environmental damages depend on the accumulated stock of pollution. Some dynamic analyses (see Kolstad 1996; Pizer 2002; Newell and Pizer 2003) suggest that in the presence of uncertainty, a carbon tax (a "price" policy) might offer substantially higher expected efficiency gains than a cap-and-trade system (a "quantity" policy).

Uncertainty and Policy Flexibility

The analyses just discussed do not consider differences across instruments in the speed at which they can adjust to new information. However, an emissions allowance system that includes provisions for the banking and borrowing of allowances might have a slight advantage over emissions taxes in this regard. For example, suppose that, under a carbon cap-and-trade system, new evidence emerges that global warming is occurring faster than projected. Speculators would anticipate a tightening of the future emissions cap, which

[11] Policymakers are also uncertain about the marginal damage schedule. However, as discussed in Weitzman (1974) and Stavins (1996), this does not have strong implications for instrument choice unless marginal damages are correlated with marginal abatement costs.
[12] The aggregate emissions cap policy could involve either fixed quotas on individual pollution sources, or a set of tradable emissions allowances, where the total number of allowances in circulation represents the aggregate cap.

would instantly shift up the trajectory of current and expected future permit prices, before any adjustment to the future cap is actually made. In contrast, under a carbon tax, it might take some time to enact a legislative change in the tax rate in response to new scientific information, which would leave emission control suboptimal during the period of policy stickiness.

Distributional Impacts

The distributional impacts of alternative environmental policies can be considered across numerous dimensions, such as regions, ethnic groups, or generations. Here we focus on two dimensions that have received especially great attention in policy discussions: the distribution between owners of polluting or energy-intensive industries and other members of society (consumers, taxpayers, workers), and the distribution across households of different incomes. These distributional impacts have important implications not only for fairness or distributive justice but also for political feasibility.

Distribution Between Owners of Polluting Enterprises and Other Economic Actors

Since the combustion of fuels is a major contributor to pollution, an important issue is the burden that pollution control policies might impose on industries supplying these fuels as well as industries (such as electricity and metals production) that use these fuels intensively. Depending on specific design features, different instruments can have very different impacts on capital owners in these industries.

Consider first the impacts of a cap-and-trade system. As discussed in Section 2, for a given quantity of allowances, free allocation leads to the same allowance prices and output price increases as does auctioning of allowances. However, the nature of the initial allocation can have a significant effect on the distributional burden from regulation.

An emissions allowance system causes firms to restrict the level of production, thereby causing an increase in the equilibrium output price. Higher output prices potentially generate rents to firms, in much the same way that a cartel enjoys rents by reducing output.

With free allowance allocation, firms enjoy these rents. In contrast, if allowances are introduced through a competitive auction, the rents are bid away as firms compete to obtain the valuable allowances. In this case, what would be firms' rents under free allocation become government revenue instead. This benefits the general taxpaying public to the extent that it reduces the government's need to rely on various existing taxes for revenue; alternatively, the public could benefit from additional government-provided goods or services financed by the auction revenue.

In fact, when allowances are initially given away for free, regulated firms might even enjoy higher profits than in the case of no regulation: the rents might more than fully compensate firms for the costs of complying with the program. Whether this occurs depends on two factors. The first is the elasticity of supply relative to the elasticity of demand for the industry's output. The greater the relative elasticity of supply, the greater the price increase associated with a given free allocation of allowances, and the larger the rents generated to firms. The second is the extent of required abatement: at low levels of abatement, allowance rents are large relative to compliance costs, which implies a greater potential for an overall increase in profit.

Studies of nitrogen oxide allowance trading under the US Clean Air Act (Bovenberg et al. 2005) and potential carbon dioxide allowance trading in the United States (Bovenberg and Goulder 2001; Smith et al. 2002; and Burtraw and Palmer 2007) suggest that the rents from 100 percent free allocation overcompensate firms for program compliance costs. In fact, these studies show that a fairly small share of the allowances—generally less than 30 percent—needs to be freely allocated to enable firms to retain rents sufficient to prevent a loss of profit.[13] It should be noted, however, that these cases involve relatively modest emission reductions. As the extent of abatement increases, the size of the rents, and hence the scope for compensation, declines relative to the compliance burden imposed on regulated industries.

Free allocation can enhance political feasibility because it avoids imposing burdens on highly mobilized producer groups. On the other hand, auctioning has an advantage in terms of cost-effectiveness because it yields revenues that can be used to finance cuts in existing distortionary taxes. From the studies above, it appears that preventing profit losses is consistent with freely allocating a small share of the allowances and auctioning the rest. In this case, the sacrifice in cost-effectiveness relative to the case of 100 percent auctioning would be fairly small. In Bovenberg and Goulder (2001), for example, partial free allocation raises policy costs by 7.5 percent relative to 100 percent auctioning. The sacrifice of cost-effectiveness could be large in some cases, however. In particular, even 100 percent free allowance allocation may not be enough to compensate firms when the proportionate emissions reduction is very large (Bovenberg et al. 2005).

Free allowance allocation is not the only way to prevent profit losses to regulated firms. Profits can also be preserved through an emissions tax system offering inframarginal exemptions to the tax—in this case, the tax applies only to emissions beyond a certain level. Like an emissions allowance system with partial free allocation, this tax policy generates rents, where the rents increase with the scope of the exemptions. Because of these rents, preserving profits may require exempting only a small fraction of the firm's emissions.

Direct regulations do not charge for remaining emissions, and thus might also impose lower burdens on regulated firms. As discussed above, however, the absence of a charge on remaining emissions implies a sacrifice of cost-effectiveness.

To date, technology mandates, performance standards, and permit systems with free allocation are all far more common than emissions taxes or fully auctioned permit systems. This suggests that owners of polluting facilities may have significantly influenced the ultimate instrument choices.

Distribution across Household Income Groups

Fairness in the distribution of cost impacts across households is a major issue for many pollution control policies—particularly those relating to energy industries—since low-income households tend to spend larger shares of their budgets on electricity, home heating fuels, gasoline, and other energy-intensive goods (Parry et al. 2006).

[13]In the first phase of the European Union's ETS, over 95 percent of the allowances were given away for free, which generated windfall profits to many of the regulated firms (Sijm, Neuhoff and Chen (2006)). Partly in reaction to this, there has been a distinct shift towards greater emphasis on the auctioning of allowances in planned future phases of the ETS, in various climate bills recently introduced in the U.S. Congress, and in the recently established Regional Greenhouse Gas Initiative in the northeast United States.

Again, the ultimate impacts of revenue-raising policies such as emissions taxes and auctioned emissions allowances depend critically on how the revenues are used. Dinan and Rogers (2002) and Metcalf (2007) examine recycling revenues from carbon taxes or auctioned carbon allowances via tax reductions favoring low-income groups (e.g., payroll tax rebates, higher income tax thresholds, lump-sum transfers). These recycling schemes can help achieve a fairer distributional burden, for example by imposing a more equitable pattern of burden-to-income ratios across different income groups. However, they might not help some elderly or other nonworking households, who may require targeted energy assistance programs.

The choice between free allocation and auctioning of allowances also has distributional implications across household income groups. In particular, free allocation tends to increase the disparity in the burden-to-income ratios between low- and high-income groups, since firms' equity values will rise with the increase in producer surplus, and upper-income groups own a disproportionate share of such equity (Dinan and Rogers 2002). In this regard, direct regulatory policies may have some appeal since they avoid transferring rents from households (through large price increases) to firms.

Conclusions

From the above discussion it should be clear that numerous dimensions are relevant to instrument choice, and that no single instrument is best along all dimensions. For example, as shown in Table 1, tradable allowance systems with free allocation might perform relatively well in terms of political feasibility (column 4) but relatively poorly in terms of minimizing general equilibrium costs or achieving household equity (columns 3 and 5). The opposite applies for (revenue-neutral) emissions taxes or auctioned allowances. Direct regulatory policies have some appeal in terms of distribution (columns 4 and 5) but are generally less cost-effective along the lines indicated by columns 1–3.

Details matter, and the general type of instrument doesn't always indicate the overall implications for cost, fairness, or political feasibility. Emissions taxes and auctioned allowances may lose some of their key attractive properties if accompanying legislation does not require offsetting reductions in other taxes. On the other hand, the political obstacles to these policies might be tempered by providing tax exemptions for some of the infra-marginal emissions, or by reserving a portion of allowances for free allocation. And the differences between emissions taxes and emission permits in the presence of abatement cost uncertainty can be blurred through provisions, such as banking and borrowing, that reduce allowance price volatility.

Technology Policies

The market failure that seems most central to environmental issues is the inability of the market to address externalities from pollution. These include local health costs, damages to ecosystems and the services they provide, costs to terrestrial and marine wildlife, and global damages such as climate change.

However, additional market failures associated with clean technology development can be inextricably linked to environmental problems, and may provide an efficiency rationale for additional instruments beyond those already discussed. In what follows, we briefly examine potential rationales and instruments for promoting technology development, focusing on two general policy objectives: advancing research and development (R&D) and promoting technology deployment.

R&D Policies

Several US states have recently announced the goal of reducing greenhouse gas emissions by 80 percent below their 1990 levels by 2050. Achieving this goal at reasonable cost would require more than substitution among known technological processes: it would necessitate major technological breakthroughs. The emissions control policies previously discussed may be incapable of bringing about these breakthrough technologies since they provide invention incentives only indirectly—by emissions pricing or by raising the costs of conventional, "dirty" production methods through direct regulation.

Additional policies to promote clean technology R&D are justified on efficiency grounds to the extent that they address market failures beyond the pollution externality. One important failure stems from the inability of inventors or innovators to fully appropriate the returns from the knowledge they create. In particular, other firms might be able to copy a new technology, legally imitate it if the technology is under patent, or otherwise use knowledge about the technology to advance their own research programs. Numerous empirical studies suggest that the (marginal) social return to innovative activity in general might be several times the (marginal) private return (e.g., Griliches 1992; Mansfield 1985; Levin et al. 1988; and Jones and Williams 1998).[14]

This appropriability problem means that incentives for clean technology R&D will be inefficiently low, even if pollution externalities are appropriately priced. There is a theoretical and empirical literature comparing the efficiency of alternative environmental policy instruments in promoting the development of cleaner technologies (e.g., Jung et al. 1996; Fischer et al. 2003; Milliman and Prince 1989). No single instrument can effectively correct market failures from both emissions externalities and the knowledge appropriability problem, however. Indeed, as Fischer and Newell (2008) and Schneider and Goulder (1997) indicate in the climate policy context, achieving a given emissions reduction through one instrument alone involves considerably higher costs than employing two instruments.[15]

The current literature does not single out any particular instrument as most effective in dealing with this problem. The relative effectiveness of subsidies to private R&D, strengthened patent rules, and technology prizes depends on the severity of the appropriability problem, the

[14]On the other hand, a "common pool" problem can work toward excessive R&D. This problem stems from the failure of a given firm to account for the fact that its own R&D reduces the likelihood that other firms will obtain innovation rents (Wright (1983)). In general, however, this rent-stealing problem appears to be dominated by the appropriability problem (e.g., Griliches (1992)).

[15]Imposing stiffer emissions prices than warranted by environmental externalities alone—instead of complementing Pigouvian pricing with tailored technology policies—is an inefficient way to promote innovation. Not only does this generate excessive short-term abatement but it also fails to differentiate among technologies that may face very different market impediments. For example, alternative automobile fuels and carbon capture and storage technologies might warrant relatively more support than other technologies, to the extent that there are network externalities associated with the new pipeline infrastructure required to transport fuels to gas stations, or emissions associated with underground storage sites.

extent of monopoly-pricing distortions under patents, and asymmetric information between governments and firms about expected research benefits and costs (e.g., Wright 1983). Also, just how much or how fast we should be pushing technology development is difficult to gauge, given uncertainty about the likelihood that research will lead to viable technologies, and the potential for crowding out other socially valuable research (e.g., Nordhaus 2002 and Goulder and Schneider 1999). Basic government research and demonstration projects can help to restore invention efforts to an efficient level. But it is difficult to quantify the efficient level of basic R&D funding toward such projects, though studies suggest that past federal spending on energy R&D to mitigate pollution and improve knowledge has often yielded considerable net benefits (NRC 2001).

Technology Deployment Policies

Once technologies have been successfully developed and are ready for commercialization, should their deployment be pushed by additional policy interventions? Again, further policy inducements are warranted on efficiency grounds only if there are additional market failures that impede the diffusion process. In theory, there are several possibilities.

Appropriability issues could arise in connection with the deployment of new technologies. Specifically, early adopters of a new technology (e.g., cellulosic ethanol production plants) could achieve lower production costs for the new technology over time through learning-by-doing. This would award external benefits to later adopters of the technology and might justify some short-term assistance for adopting the new technology. Since the potential for deployment-related knowledge spillovers may vary greatly depending on the product involved, these policies need to be evaluated on a case-by-case basis.

Another potential market failure relates to consumer valuations of energy-efficiency improvements. Some analysts argue that consumers systematically undervalue such improvements. Possible evidence for this is the tendency of consumers to require very short payback periods for durable energy-using equipment—in effect, to apply discount rates significantly above what might be considered the social discount rate.[16] Greene (1998) cites these problems in claiming that there is a role for automobile fuel economy regulations, as a complement to emission pricing instruments. This issue has long been contentious. Solid empirical research is needed to sort out whether there is a significant additional market failure here and therefore whether additional government incentives are justified on efficiency grounds.

Lack of information could also cause consumers to undervalue (or overvalue) improvements in energy-efficiency. As pointed out by Jaffe and Stavins (1994), the market only "fails" if the costs of providing additional information fall short of the benefits. If the market does fail, the most efficient policy response is to subsidize or require the provision of better information to the consumer (e.g., requiring auto dealers to post certified fuel economy stickers on vehicles).

[16]Clearly many economists support the idea that the social rate of discount is lower than the market rate of interest (see, for example, Marglin (1963)), which implies that, from the point of view of social welfare, consumers tend to discount the future too heavily in their choices of consumer durables or, more broadly, in their saving decisions. This provides a rationale for government support of broad savings incentives rather than incentives focused only on saving in the form of purchases of energy-efficient durable goods.

Conclusions about Technology Policies

In sum, there are strong arguments for invoking technology-advancement policies in addition to instruments aimed at curbing emissions or effluent. Multiple market failures justify multiple instruments. Most agree that additional policies are warranted to support basic and applied research, development, and demonstration projects at government, university, and private institutions, though the specific instruments and level of support are less clear. There is less agreement regarding the justification for measures to promote market deployment once new technologies have been successfully developed. Whether such policies are called for seems to depend on the specific industries or processes involved, as well as assumptions about consumer behavior that deserve further empirical testing.

Additional Challenges to Instrument Choice

We now consider three issues that further complicate instrument choice: multiple externalities from a single product or service; the potential for interactions among policy instruments; and the possibility of linking instruments across jurisdictions.

Multiple Externalities

One potential attraction of taxes on electricity, gasoline, or other goods related to emissions is that they may reduce demands for goods whose production or consumption involves multiple externalities. For example, by reducing gasoline consumption a gasoline tax helps address externalities from tailpipe emissions, such as local pollution and global climate impacts; and, by increasing the fuel costs per mile driven, the tax deters vehicle use and thereby reduces externalities from traffic congestion and traffic accidents (to the extent that insurance does not internalize accident risks from driving). Thus, this one tax can accomplish several goals. Apart from administrative considerations, the most cost-effective approach is to introduce multiple taxes. Each tax would be set based on the marginal external cost of a different externality, which would yield appropriate incentives to deal with each of the various problems (emissions, congestion, etc.) involved. On the other hand, the use of multiple taxes can involve substantial administrative costs. Policy makers need to weigh such costs against the potential benefits from implementing multiple, sharply focused taxes.

Regulatory Interactions

Preexisting policies may have implications for the choice of emissions control instruments. Prior regulations on electricity pricing provide an example. In the majority of states that retain average-cost pricing for power generation, prices are often below marginal supply cost. This reflects the fact that older, baseload technologies, such as coal and nuclear generation, tend to have lower variable costs than new or marginal technologies, such as natural gas generation. In these circumstances, the price of electricity is not only below social cost (which includes the environmental cost), but below the marginal private supply cost as well.

In this setting, Burtraw et al. (2001) find that the costs of moderately reducing power plant emissions of CO_2 are about two-thirds lower under auctioned permits than under the performance standards. This is because auctioned permits have a greater impact on electricity prices, as firms must pay for remaining emissions under auctioned permits. Thus, in this setting auctioned permits have an advantage by helping to prices closer to marginal social cost. Burtraw et al. also find that auctioned permits are far less costly than freely allocated permits. This reflects the fact that regulated utilities cannot pass forward the market value of freely allocated permits through higher generation prices.

Multiple Jurisdictions, Leakage, and Policy Linkages

Environmental problems are often addressed by several different jurisdictions and multiple levels of government. This can also have implications for instrument choice.

One important issue is "emissions leakage," where increases in emissions outside of a given jurisdiction offset the reductions promoted within the jurisdiction. Leakage can occur in at least two ways. First, new regulations within one jurisdiction can raise production costs, causing polluting firms to relocate to another jurisdiction. Second, new regulations imposed by one jurisdiction can shift consumer demands away from (higher priced) goods produced within that jurisdiction, leading to increased demands and emissions elsewhere. Although the use of any instrument that raises costs can generate leakage, some instruments might cause more leakage than others. In this regard, certain direct regulatory instruments such as renewable portfolio standards could be superior to cap-and-trade in preventing leakage associated with a shift in demands. In particular, they might minimize a shift from electricity generated within a jurisdiction (e.g., California) to electricity generated elsewhere (outside of California). This is because direct regulatory instruments do not charge for inframarginal emissions and thus are likely to have a weaker impact on within-jurisdiction electricity prices, implying less leakage. This advantage would have to be weighed against any disadvantages in terms of general cost-effectiveness.

Another important consideration is the potential for policy linkages across jurisdictions. If political constraints force environmental policies to be made by governments whose jurisdictions are narrower than what is efficient, the situation can be improved through linkages across regional programs. For example, the cost-effectiveness of various governments' cap-and-trade systems to reduce greenhouse gases can be enhanced by linking the systems, as this yields a broader market and an equating of marginal abatement costs across regions. (Similarly, harmonizing carbon taxes across jurisdictions enhances cost-effectiveness.) In this regard, the relative attractiveness of different instruments to one jurisdiction may depend importantly on the extent to which these instruments mesh with policies previously implemented by other jurisdictions. Thus, in the United States, the fact that 10 northeastern states have already committed themselves to a joint cap-and-trade system (the Regional Greenhouse Gas Initiative) increases the attractiveness of cap-and-trade to other states.

Conclusions

Environmental economists should take pride in the substantial body of literature on instrument choice that has emerged since the work of the "founding fathers" (e.g., Kneese and Bower 1984) in the 1960s. Beyond providing insights into the implications of existing regulatory approaches, environmental economists have helped devise new instruments for combating pollution, and their analyses have had a significant and growing impact on public policy. Moreover, many of the insights concerning environmental policy instruments are relevant to instrument choice or policy design in other areas, including forestry and fisheries, agriculture, transportation, substance abuse, and health.

Notwithstanding our claim that no single instrument is superior to all others in all settings, the analyses in the instrument choice literature have made a strong case for the wider use of flexible, incentive-based policies. They have also helped establish the idea that environmental taxes and auctioned allowances are a particularly efficient potential source of government revenue. Flexible incentive-based instruments that only existed on paper a few decades ago—such as emissions allowance banking and a "safety valve"—are now becoming part of the regulatory landscape. Economists' calls for increased auctioning (rather than free allocation) of allowances are being heeded in the EU's recent proposals for its Emissions Trading Scheme (Commission of the European Communities 2008), as well as in plans for the Regional Greenhouse Gas Initiative in the northeastern United States.

Despite these achievements, significant challenges remain. Discussions of alternative instrument choices often leave something to be desired. Many analyses disregard administrative, legal, or institutional issues relevant to policy costs, or focus exclusively on cost-effectiveness. As emphasized above, a broad range of criteria deserves consideration. In addition, many studies ignore details about market structure or producers' objectives that can influence the relative effectiveness of various instruments.

Government (as opposed to market) failure represents a further challenge. Winston (2007) offers many examples of government intervention in markets where the evidence of a market failure is tenuous at best. Even when there is a clear rationale for policy intervention, inefficient instruments (such as ethanol mandates) may be employed at the expense of far more cost-effective alternatives (such as fuel taxes and CO_2 taxes). Government failures are due in part to the influence of powerful interest groups. Such influence is more a difficulty with the political process than an economics problem. Nevertheless, economists can contribute to improved political outcomes by devising new policy instruments that do a better job reconciling cost-effectiveness and distributional goals (such as avoiding large, near-term burdens on highly mobilized stakeholders). They can also improve the prospects for sound policy by becoming more effective in communicating key research insights to policymakers.

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