Vertical Targeting: Issues in Implementing Upstream versus Downstream Regulation

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Regulators face a choice of where in a vertical chain to set environmental regulation.[1] Regulation that targets upstream sources of greenhouse gases focuses on firms producing (or importing) coal, natural gas, oil, and refined petroleum products. Downstream regulation may directly regulate pollution sources (*e.g.*, motor vehicles, farms, and power plants) or perhaps focus further downstream by regulating consumer goods (*e.g.*, retail electricity). This paper reviews why direct regulation can minimize regulatory costs. I discuss how transactions costs, offset programs, and international trade affect the optimal choice of where to vertically target environmental regulation.

1 Theory of Cost Effectiveness

A large literature has established that direct regulation of pollution sources is cost effective relative to input regulations.[2] This model provides a simple way to measure these advantages. Suppose that price-taking firm i produces a single good that results in carbon emissions. The

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[1] A growing literature on upstream versus downstream regulation includes Driesen and Sinden (2009), Hobbs, Bushnell, and Wolak (2010), Mansur (forthcoming), and Metcalf and Weisbach (2009).

[2] See, for example, Burrows (1977), Carlton and Loury (1980), Schmalensee (1976), and Smith (1992).

firm maximizes profits π with respect to its output q, the carbon content of its fuel F (c/q), and its end-of-pipe emissions rate r (a fuel's fraction of carbon emitted):

$$\max_{q,F,r} \pi = Pq - c(q) - a_{in}(q, F) - a_{end}(q, F, r), \tag{1}$$

where P is the price of the good sold, $c(q)$ is production costs, $a_{in}(q, F)$ is input-based abatement costs, and $a_{end}(q, F, r)$ is "end-of-pipe" abatement costs. Switching to lower carbon inputs, like from coal to natural gas, is in a_{in}, while installing carbon capture and storage (CCS) is in a_{end}. Unregulated firms set marginal production costs equal to price $(P = c'(q))$ and do not abate: $r = 1, a_{in} = 0, a_{out} = 0$.

An upstream policy, like a coal tax, will only affect firms' choices of inputs. Let t_{in} be an input-based carbon price. Here, the firm's first order conditions imply:

$$P - c'(q) - \partial a_{in}/\partial q - \partial a_{end}/\partial q = t_{in}F, \tag{2}$$

$$-\partial a_{in}/\partial F - \partial a_{end}/\partial F = t_{in}q. \tag{3}$$

In contrast, a policy regulating emissions directly, τ_{out}, results in the following conditions:

$$P - c'(q) - \partial a_{in}/\partial q - \partial a_{end}/\partial q = \tau_{out}Fr, \tag{4}$$

$$-\partial a_{in}/\partial F - \partial a_{end}/\partial F = \tau_{out}rq, \tag{5}$$

$$-\partial a_{end}/\partial r = \tau_{out}Fq. \tag{6}$$

Cost-effective regulations allow firms to use any abatement method but require regulators to monitor emissions rates. When feasible, like in the case of power plants that use Continuous Emissions Monitoring Systems, firms will choose among all possible ways of reducing pollution. An optimal policy sets $t_{in} = 0$ and $\tau_{out} = \delta$, the marginal damages from emissions.[3] From equations (4), (5), and (6), we see that firms have an incentive to abate until the carbon price τ_{out} equals the marginal abatement cost along *all* margins:

$$\tau_{out} = MAC_{out} \equiv \frac{P - c'(q) - \frac{\partial a_{in}}{\partial q} - \frac{\partial a_{out}}{\partial q}}{Fr} = -\frac{\frac{\partial a_{in}}{\partial F} + \frac{\partial a_{out}}{\partial F}}{rq} = -\frac{\partial a_{out}/\partial r}{Fq}. \tag{7}$$

Given similar incentives across firms, this policy is expected to be cost effective. In contrast, under an input-based regulation, firms have no incentive reduce r.

Had an upstream policy been used to regulate acid rain, firms would have had an incentive to switch to low-sulfur coal but not to install flue gas desulferization. The Clean Air Acts' 1990 trading program has resulted in many scrubber installations, suggesting an input-based regulation would have been relatively costly. In the context of CO_2, CCS's high costs may make direct regulation unnecessary. For automobiles, end-of-pipe abatement also seems prohibitively expensive given current technology.

The incremental costs incurred by regulating upstream at link v of the vertical chain ($AbateCost_v$) can be measured for a given abatement goal, $\widehat{A}$. Define the marginal abatement costs from input-based regulations, MAC_{in}, that are derived from (2) and (3). Let MAC_{end} be those abatement methods that would be options under direct pollution regulation, as in (7), but that are not in MAC_{in}: $MAC_{end}^{-1}(A) \equiv MAC_{out}^{-1}(A) - MAC_{in}^{-1}(A)$. Optimal regulation may have a mix of end-of-pipe and input-based methods. Let A_v^* be optimal amount of abatement from input-based methods. Thus:

$$AbateCost_v = \int_{A_v^*}^{\widehat{A}} MAC_{in}^v(x)dx - \int_{A_v^*}^{\widehat{A}} MAC_{end}^v(x)dx. \tag{8}$$

[3] Regulators could levy a tax τ_{out} or allocate permits such that the permit price equals τ_{out}.

Under the theoretical assumptions above, the flexibility of direct regulation achieves the lowest overall costs (*i.e.*, $AbateCost_v = 0$ when the v^{th} link pollutes). However, regulating at the source of pollution may fail to realize these gains from trade for several reasons including transactions costs, offsets, and international trade.

2 Transactions Costs

The cost of monitoring and enforcing regulation for millions of cars, houses, and offices could dwarf the incremental benefits from direct regulation (*i.e.*, $AbateCost$). However, upstream regulation could substantially reduce these transactions costs. Metcalf and Weisbach (2009) note that regulating a few thousand fossil-fuel producing companies would account for 80 percent of GHG emissions in the US. By including some select non-fossil polluters, an additional 10 percent of total emissions would be regulated. Metcalf and Weisbach (2009) argue that the transactions costs of adding these polluters would be modest.

Suppose regulators incur costs $TransCost(n)$ in determining emissions from n sources, where $TransCost'(n) > 0$. In addition, monitoring the usage and carbon content of each fuel also results in costs. For simplicity, assume the same cost function $TransCost(m)$ that society incurs on m input suppliers. Direct regulation incurs cost $TransCost(n)$ while upstream regulation incurs higher abatement costs and some transactions costs $AddCost + TransCost(m)$. In order to minimize overall costs, regulators may regulate any of V vertical links associated with carbon emissions from one particular industry. Note that transactions costs depend on technology. As monitoring technology improves, more complex vertical levels become feasible.

3 Offsets

With upstream regulation, regulators may offer firms credit for installing end-of-pipe abatement technologies. These credits can partially offset firms' regulatory obligations. On the one hand, this may allow society to achieve emissions reduction goals at a lower cost. However, offset programs may increase emissions.

Emissions may increase with offsets because of asymmetric information. In order to entice firms to abate at the end of the pipe when regulators are only regulating fuel inputs, firms need a subsidy. With perfect information, optimal credits equal actual abatement. Define the regulators' perceived abatement as $\overline{\alpha} \equiv \overline{e} - e$ and the actual abatement as $\alpha \equiv e^0 - e$, where $e = qFr$, and $\overline{e}$ and e^0 are perceived and actual business-as-usual emissions.

When regulators do not know how much firms would have polluted but for the abatement action, then either they will overstate the level of abatement, $\overline{\alpha} > \alpha$, or understate it. Both may result in inefficiencies. If abatement levels are understated, then some firms with low costs may decide not to offer offsets because the number of credits given out are insufficient to cover costs. To see this, assume that the firm faces the following problem:

$$\max_{q,F,r} \pi = Pq - c(q) - a_{in}(q, F) - a_{out}(q, F, r) - t_{in}Fq + \sigma(r, \overline{e}), \tag{9}$$

The subsidy σ commonly takes the form of pollution credits for perceived abatement. Regulated firms may use these offset credits in lieu of regulated emissions permits. In equilibrium, these credits would sell at the market price of permits (assuming no trading restrictions): $\sigma(r, \overline{e}) = t_{in} \cdot (\overline{e} - qFr)$. Thus the firm will opt in to the offset program only if doing so increases profits:

$$
\begin{aligned}
& Pq^* - c(q^*) - a_{in}(q^*, F^*) - a_{out}(q^*, F^*, r^*) - t_{in}F^*q^* + t_{in} \cdot (\overline{e} - q^*F^*r^*) \qquad (10) \\
> \; & Pq^{**} - c(q^{**}) - a_{in}(q^{**}, F^{**}) - t_{in}F^{**}q^{**},
\end{aligned}
$$

where (q^*, F^*, r^*) and (q^{**}, F^{**}, r^{**}) are the optimal choices with and without opting in, respectively. If $q^* = q^{**}$ and $F^* = F^{**}$, then (10) implies the subsidy must weakly exceed end-of-pipe abatement costs: $t_{in} \cdot (\overline{e} - q^*F^*r^*) > a_{out}(q^*, F^*, r^*)$. When $\overline{e}$ is small, opting in may not be profitable, even when it is socially optimal to do so.

In contrast, when there are too many credits awarded, firms are more likely to select into the program. As actual abatement is less than the credits that are used to offset regulatory obligations, the overall level of emissions increases with offsets. This adverse selection effect has been shown in other markets (for example, see Montero (1999)). In addition, if the credits are sufficiently greater than the actual abatement and the abatement decision is lumpy, then abatement costs could even *increase* with offsets (see Mansur (forthcoming)).

The overall welfare benefits of offsets ($Offsets_v$) of regulating link v equal the cost savings less the additional damages. The cost savings are from replacing some regulated firms (who, at the margin, have marginal abatment costs equal to the emissions price t_{in}) with lower cost offsets. The additional damages occur when credits exceed actual abatement, $\delta \cdot (\overline{\alpha} - \alpha)$. Thus:

$$Offsets_v = \sum_{i=1}^{l(v)} \left\{ \mathbf{1}\left[OptIn\right] \cdot \left[(t_{in}\alpha_i - a_{out}(q_i^*, F_i^*, r_i^*) - \delta \cdot (\overline{\alpha} - \alpha) \right] \right\}, \qquad (11)$$

where $\mathbf{1}\left[OptIn\right]$ indicates opting in, based on (10), and $l(v)$ is link v's firm count. While regulators cannot observe e^0 for each firm, they may know its distribution. In this case, the expected benefits from offsets, $E[Offsets_v]$, can help determine the least costly policy.

4 International Trade

International trade has implications for the effectiveness of upstream versus downstream regulation. If trading nations do not harmonize carbon prices, then this incomplete regulation affects production and consumption. *Leakage* occurs when partial regulation results in an increase in emissions in unregulated parts of the economy.[4] In the case of a net exporting industry, upstream production regulation may reduce emissions relative to a regulation that is only on domestic consumption. Therefore, international trade has implications for the effectiveness of environmental policy throughout the vertical chain of an industry.

Consider two vertical industries that each competes internationally. Regulators may regulate upstream or down. Assume that there are no international emissions policies. The competitive markets are made up of four groups of firms: upstream domestic supply, S_{up}^{dom}, upstream foreign supply, S_{up}^{for}, and the corresponding downstream supply, S_{down}^{dom} and S_{down}^{for}, respectively. Demand is similarly composed: D_{up}^{dom}, D_{up}^{for}, D_{down}^{dom}, and D_{down}^{for}. Assume that all firms can abate. Regulators may target any of the domestic entities: S_{up}^{dom}, S_{down}^{dom}, D_{up}^{dom}, or D_{down}^{dom}. Note that the effectiveness of these policies depend on the elasticities of all domestic and foriegn supply and demand, as well as whether the regulated industries export or import. If firms export (on net), then a production policy may reduce more carbon than

[4]Many recent papers examine leakage including Bushnell and Chen (2009), Bushnell, Peterman, and Wolfram (2008), Fischer and Fox (2009), and Fowlie (2009).

a consumption policy with a similar carbon price. On the other hand, if the industry is a net importer, leakage is more likely to be an issue.

As an example of leakage, suppose that there is just one industry and all the demand is domestic. The domestic firms' residual demand is: $RD^{dom}(P) = D^{dom}(P) - S^{for}(P)$. Decomposing market demand into $RD^{dom}(P)$ and $S^{for}(P)$ helps see the relationship between leakage and vertical targeting. In particular, if market prices increase in equilibrium, residual demand for domestic firms will fall because consumers buy less (which reduces emissions) and foreign firms produce more (which will increase emissions). Thus, regulating segment v results in leakage ($Leakage$), which increases emissions and causes environmental damages:

$$Leakage_v = \delta \widetilde{F} \widetilde{r} \left[S^{for}(P_1) - S^{for}(P_0)) \right], \tag{12}$$

where $\widetilde{F}$ and $\widetilde{r}$ represent foreign firms' fuel carbon content and end-of-pipe emissions rate, and P_1 and P_0 denote the price of good v with and without regulation, respectively. All else equal, a policy that aims at the part of the vertical chain with the least elastic foreign supply will result in the greatest welfare.

Combining all four components–cost effectiveness, transactions costs, offsets, and international trade–the link v^* minimizes total social costs:

$$v^* = \arg \min_{v \in \{1,..,V\}} \{AbateCost_v + TransCost(l_v) - E[Offsets_v] + Leakage_v\}, \tag{13}$$

where l_v equals the number of agents in segment v (*e.g.*, n or m).

5 Conclusions

Regulators face several key issues in deciding what level of a vertical chain of industries to target. This paper examines several reasons why potential gains from trade may not be realized. First, upstream regulation could substantially reduce transactions costs. Metcalf and Weisbach (2009) find that regulating a few thousand fossil-fuel producing companies would account for 80 percent of GHG emissions. Second, offsets have been considered in order to give firms facing upstream regulation with the incentive to choose some downstream options to reduce emissions. While these offsets may result in lower overall abatement costs, they may also have unintended consequences that result in less overall abatement. Third, if all nations do not harmonize carbon prices, then incomplete regulation will affect the types of goods produced, traded, and consumed. The magnitude of regulatory leakage depends on whether policy regulates firms upstream or downstream. The optimal choice of vertical targeting in setting environmental regulation depends on these four factors: cost effectiveness, transactions costs, offsets and international trade.

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