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Chapter Author(s): Erin T. Mansur

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11

Upstream versus Downstream Implementation of Climate Policy

Erin T. Mansur

11.1 Introduction

This chapter examines the trade-offs of regulating greenhouse gases (GHG) upstream versus downstream. Upstream regulation focuses on firms producing or importing raw materials that contain GHG like coal, natural gas, and refined petroleum products. In contrast, downstream regulation typically refers to regulating the direct sources of GHG, including motor vehicles, farms, power plants, and other stationary sources. The implications of which sectors to target will depend on four issues discussed in the following: cost-effectiveness, transactions costs, leakage, and offsets.

Before examining these issues, this chapter explores the terms "upstream" and "downstream." Regulation may occur at many different segments of a vertical chain. For this reason, I will refer to the choice of upstream versus downstream regulation as one of regulatory vertical segment selection, or *vertical targeting.* Some industries have short chains, while others have many links.

For example, consider the regulation of carbon dioxide (CO_2) emissions from personal vehicles. The chain begins with worldwide exploration and extraction of crude oil. Firms extract most of the oil used for US transportation internationally. The United States only produces a third of the oil that it consumes (United States Energy Information Administration [EIA] 2008).

Erin T. Mansur is associate professor of economics at Dartmouth College and a research associate of the National Bureau of Economic Research.

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In the second vertical segment, firms transport crude by pipeline or tanker. Third, the oil reaches a refinery, most likely one of the 150 refineries in the United States. Imports account for approximately 12 percent of US motor gasoline consumption (EIA 2008). Fourth, after refining the crude oil into motor gasoline, the product moves, typically by pipeline, to about 390 major wholesale racks.[1] Fifth, trucks bring it to approximately 105,000 US gasoline stations (United States Census Bureau 2010). Sixth, consumers purchase and pump the gasoline into over 244 million private and commercial registered motor vehicles in the United States (Department of Transportation 2009). While firms and consumers release CO_2 emissions in all six links, in this case, the vast majority occurs during consumption of the final product.

This example illustrates two points regarding vertical targeting. First, the number of firms or consumers involved in each step may differ dramatically. As discussed in the following, optimal regulation occurs at the pollution source (assuming an otherwise functioning market). However, the number of refineries pales in comparison to the number of registered vehicles. If few opportunities exist to abate CO_2 downstream of refining—namely, if wholesale racks, gasoline stations, and motor vehicles cannot sequester some of the carbon content in the gasoline at marginal costs equal to or below carbon prices—then regulating at the refinery level will result in small losses in cost-effectiveness from potential trades but great savings in transactions costs.

Second, the terms "upstream" and "downstream" do not define a specific vertical segment. The upstream industry could mean any one of several industries. In this example, upstream typically refers to refineries, while downstream refers to vehicles. However, in other contexts, "upstream" might mean the polluters and "downstream" might mean consumers. For example, in electricity markets, upstream regulation targets power plants, while downstream refers to regulating retailers, the load serving entities (LSEs). Downstream regulation would require estimating the source of electricity for each LSE and using a carbon price at that level of the vertical chain. The terminology of upstream and downstream must be understood in context. This chapter aims to address: (a) why, in a general setting, regulating polluters directly maximizes social welfare and (b) why this might not apply for carbon policy.[2] In particular, if policies do not target polluters, would a regulation upstream of the pollution source be more cost-effective, or would a downstream one be preferred?

In the following sections, I develop a theoretical model that explains why regulating the source of pollution lowers abatement costs. In particular, if firms can reduce emissions at the end of the pipe, upstream regulations

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[1] Oil Price Information Service (OPIS) collects wholesale gasoline and diesel prices for over 390 racks (http://www.opisnet.com/rack.asp, accessed April 15, 2010).

[2] For simplicity, I will refer to all GHG emissions and regulations as carbon emissions and carbon policy, respectively. See the Intergovernmental Panel on Climate Change Fourth Assessment Report (Solomon et al. 2007) for an explanation of the science of converting various GHG emissions into carbon dioxide equivalent emissions.

may miss these options. Next, I discuss three mechanisms that may affect regulators choice of vertical targeting and how one could account for them in determining a least-cost policy. First, transactions costs from monitoring and enforcing regulations differ dramatically along the vertical chain given the number of consumers or producers involved at each segment. Second, while policy discussions include concerns of leakage, I note how the choice of vertical targeting will affect the degree of leakage. Namely, the supply elasticity of unregulated firms varies by segment. Last, if the point of regulation lies upstream of the pollution source, offsets can reward firms for choosing to abate downstream. I discuss how these offset programs may affect the total costs of a regulation for a given vertical chain. Many consider offsets to provide a trade-off: lower abatement costs but increase total emissions. I show that offsets may even increase both costs and emissions. Taking account for all four aspects of vertical targeting—cost-effectiveness, transactions costs, leakage, and offsets—this chapter provides a model of how costs vary along a vertical chain. The chapter concludes with a brief discussion of other potential issues with vertical targeting and a summary of the main findings.

11.2 Theory of Cost-Effectiveness

This section examines the relative cost-effectiveness of upstream versus downstream regulation.[3] Suppose that firm i produces a single good that results in carbon emissions. The firm maximizes profits π with respect to its output q, the carbon content of its fuel F (measured in carbon/q), and its end-of-pipe emissions rate r (measured as the fraction of a fuel's carbon emitted):

$$(1)\qquad \max_{q,F,r} \pi = P(Q)q - c(q) - a(q, F, r),$$

where the price of the good sold (P) depends on the total industry output Q, and firm costs are denoted $c(q)$ for production (given no carbon regulation) and $a(q, F, r)$ for abatement. Note that Fr equals the typical emissions rate definition. For a given competitive quantity-choosing environment, an unregulated firm will set marginal revenue ($\text{MR} \equiv \partial P(Q)q / \partial q$) equal to marginal cost ($\text{MC} \equiv c'(q)$) and not abate: $r = 1$, $a = 0$.

Next I write $a(q, F, r)$ as two additive components: $a_{\text{in}}(q, F)$ depending only on inputs, and $a_{\text{out}}(q, F, r)$ for "end-of-pipe" technologies. Switching to a lower carbon fuel (for example, a vehicle switching from oil-based diesel to biodiesel, or a power plant switching from coal to natural gas) would be

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[3] This chapter relates to several literatures. Schmalensee (1976) compares upstream versus downstream welfare measurements of input-based taxes. The environmental costing literature notes the practical importance of making both inputs and outputs reflect social costs (Smith 1992). Burrows (1977) modeled the input substitution implications of pollution taxes relative to standards. Carlton and Loury (1980) consider the entry and exit implications of taxation policy.

in a_{in}. a_{out} includes other technologies, like installing carbon capture and sequestration (CCS) technology on a power plant, but also any other type of abatement decision that would not be covered by changing inputs. For example, if a refinery changed the product mix to produce more asphalt (which would sequester carbon), then this would also be part of a_{out}.

Consider two possible regulations: a carbon price as an input-based regulation t_{in}, and a carbon price as an end-of-pipe regulation τ_{out}. We can rewrite the firm's objective function in equation (1) as:

$$\text{(2)} \qquad \max_{q,F,r} \pi = P(Q)q - c(q) - t_{\text{in}}F\bar{r}q - \tau_{\text{out}}Frq - a_{\text{in}}(q,F) - a_{\text{out}}(q,F,r),$$

where $\bar{r}$ corresponds to the emissions rate of the firm's unregulated fuel choice. As mentioned in the preceding, an unregulated firm would not abate, $\bar{r} = 1$. In this setting, I write the first-order conditions as:

$$\text{(3)} \qquad q : t_{\text{in}}F + \tau_{\text{out}} = MR - c'(q) - \frac{\partial a_{\text{in}}}{\partial q} - \frac{\partial a_{\text{out}}}{\partial q},$$

$$\text{(4)} \qquad F : t_{\text{in}}q + \tau_{\text{out}}rq = \frac{-\partial a_{\text{in}}}{\partial F} - \frac{\partial a_{\text{out}}}{\partial F},$$

$$\text{(5)} \qquad r : \tau_{\text{out}}Fq = \frac{-\partial a_{\text{out}}}{\partial r}.$$

A cost-effective regulation would allow firms to use any means of abating pollution, whether it be end of pipe, input based, or just producing less output. In this case, the regulator would need to be able to monitor the actual emissions rate, r. When feasible, like in the case of power plants that use a continuous emissions monitoring system (CEMS), firms will choose among all possible ways of reducing carbon. To enact this, regulators would set $t_{\text{in}} = 0$ and, if socially optimal, $\tau_{\text{out}} = \text{MD}$, the marginal damages from carbon emissions.[4] From equations (3), (4), and (5), we see that firms have an incentive to reduce pollution on *all* margins and to continue to abate until the carbon price τ_{out} equals the marginal abatement cost (MAC):

$$\text{(6)} \qquad \tau_{\text{out}} = \text{MAC}_{\text{out}} = \frac{\text{MR} - c'(q) - (\partial a_{\text{in}} / \partial q) - (\partial a_{\text{out}} / \partial q)}{Fr}$$

$$= -\frac{(\partial a_{\text{in}} / \partial F) + (\partial a_{\text{out}} / \partial F)}{rq} = -\frac{\partial a_{\text{out}} / \partial r}{Fq}.$$

All regulated firms would have similar incentives. Hence, the marginal cost of abatement will be equal across all techniques and all firms: the result being cost-effective.

In contrast, an input-based regulation would set $\tau_{\text{out}} = 0$ and, in order

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[4] Under a tax, regulators would levy a tax τ_{out}, while under a cap-and-trade regulation, permits would be auctioned or grandfathered such that the expected permit price equals τ_{out}.

to be allocatively efficient, t_{in} = MD.[5] In this case, from equation (5), we see that firms have no incentive to abate using end-of-pipe technologies. Furthermore, only under an end-of-pipe regulation, the marginal abatement cost from reducing output or changing inputs depends on the choice of r. While firms will still have incentives to reduce output and improve the carbon content of fuels, some opportunities to abate will be forgone. In equilibrium, all firms would set:

$$(7) \qquad t_{\text{in}} = \text{MAC}_{\text{in}} = \frac{\text{MR} - c'(q) - (\partial a_{\text{in}} / \partial q) - (\partial a_{\text{out}} / \partial q)}{F}$$

$$= -\frac{(\partial a_{\text{in}} / \partial F) + (\partial a_{\text{out}} / \partial F)}{q}.$$

If such an approach had been used for sulfur dioxide regulation twenty years ago, firms would only have incentive to switch to low-sulfur coal and not to install scrubbers. Given the number of scrubbers that have been installed because of Title IV of the 1990 Clean Air Act Amendments, an input-based regulation may have been quite costly in that case. In the context of CO_2, CCS's high capital costs may make end-of-pipe opportunities less relevant.

In order to measure the additional costs of using an input-based regulation, one would need to be able to estimate the marginal abatement cost for all techniques. Figure 11.1 depicts how these costs might be determined. As Metcalf and Weisbach (2009) note, a narrow policy will miss out on some opportunities and will result in a steeper marginal abatement cost curve. Figure 11.1 shows this in a slightly different way. The horizontal axis shows the overall amount of abatement required, aggregating over all polluters, by the policy $\hat{A}$. The left vertical axis maps input-based marginal abatement costs, MAC_{in}, as in equation (7). The right vertical axis represents the marginal costs only for end-of-pipe abatement, MAC_{end}. This includes those incentives outlined in equation (6) but not in equation (7):

$$(8) \qquad \text{MAC}_{\text{end}}^{-1}(A) \equiv \text{MAC}_{\text{out}}^{-1}(A) - \text{MAC}_{\text{in}}^{-1}(A).$$

In other words, MAC_{end} accounts for the abatement options resulting from changing r. Where the marginal costs equate ($\text{MAC}_{\text{in}} = \text{MAC}_{\text{end}}$) at A^*, firms achieve the least-cost option. The shaded area shows the additional costs (AddCost) that firms incur by only being rewarded for changing q and F:

$$(9) \qquad \text{AddCost} = \int_{A^*}^{\hat{A}} \text{MAC}_{\text{in}}(x)dx - \int_{A^*}^{\hat{A}} \text{MAC}_{\text{end}}(x)dx.$$

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[5] This section looks at extremes of regulating only one vertical segment. However, some combination of upstream and downstream policies could provide incentives for lowering abatement costs but also keep transactions costs low (for example, see Fullerton and Wolverton 2000). The discussion of offsets revisits this issue.

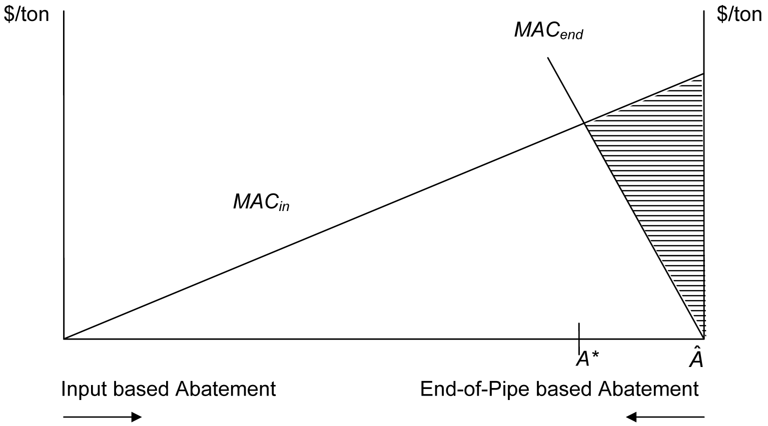

Fig. 11.1 Depiction of marginal abatement costs broken into input-based and other, end-of-pipe abatement

Notes: The horizontal axis is the total amount of abatement required under the cap. The shaded area is the additional costs incurred by only allowing input-based abatement methods to be used.

Under the theoretical assumptions in the preceding, flexibility achieves the lowest overall costs. As a starting point, downstream regulation appears to be the cost-effective policy. Furthermore, dynamic incentives may exacerbate this finding. Firms would have incentive to develop, and invest in, new end-of-pipe abatement technologies if the carbon price were on emissions but not if they face an input-based policy.

11.3 Three Main Concerns of Vertical Targeting

However, regulating at the source of pollution may fail to realize these gains from trade for several reasons. This section highlights three: transactions costs, leakages, and offsets. Transaction costs recognize that monitoring and enforcement become more complex when a vertical segment includes many polluters. Leakage occurs when unregulated firms emit more because of the policy. Vertical targeting will affect leakage: unregulated firms in some vertical links will be more price elastic than others. Upstream policies coupled with offsets may allow for cost-effectiveness. However, asymmetric information could result in greater emissions and greater costs with offsets than without them. The following section discusses some other issues that have been raised on this issue.

11.3.1 Transactions Costs

Transactions costs pose a major hurtle for establishing an end-of-pipe regulation: the cost of monitoring and enforcing regulation for millions of pollution sources could dwarf the benefits from some downstream regulations. In contrast, a regulation upstream of pollution sources could substantially reduce these 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 United States. By including some select nonfossil 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.

I modify the theory from the previous section to account for these costs. Suppose that regulators incur a cost κ in determining emissions from *each* source. In addition, monitoring the usage and carbon content of each fuel also results in costs. For simplicity, assume the same constant cost κ that society incurs on each input supplier. Furthermore, assume that the decision to regulate upstream or downstream—that is, input-based or end of pipe—is jointly determined for all n pollution sources and m fuel suppliers. A regulator trying to minimize costs now faces a trade-off: regulate end of pipe and incur costs $n\kappa$, or regulate inputs and incur higher abatement costs and some transactions costs AddCost + $m\kappa$. Note that if $m > n$, then end-of-pipe regulation will always be lower cost (assuming similar transactions costs per firm).

As discussed in the motor vehicle example at the start of this chapter, many segments in the vertical chain could be regulated. In order to minimize overall costs, regulators may consider all V options, where V equals the number of vertical links associated with carbon emissions from one particular sector or industry. Let v^* solve the cost minimization problem:

$$v^* = \arg \min_{v \in \{1, \ldots v\}} \{\text{AddCost}_v + l_v \kappa\}, \tag{10}$$

where l_v equals the number of agents in segment v (e.g., n or m). Note that for the polluting segment, AddCost = 0.

In general, moving further upstream (or downstream) from the source of pollution results in forgoing some abatement opportunities. Hence, I expect AddCost to increase monotonically with vertical distance from the pollution source. However, the number of regulated firms may increase or decrease along the vertical chain. In the vehicle example, while the number of vehicles vastly exceeds refineries, more firms extract oil worldwide than own US refineries.

Finally, note that transactions costs depend on technology. In the future, technology will likely improve such that collecting and using information for enforcement becomes even easier. As a result, the cost of regulating more complex vertical levels will likely fall; regulating 250 million vehicles may become feasible. In other words, the optimal vertical targeting of regulation may change over time.

11.3.2 Leakage

Leakage poses a second major concern of upstream versus downstream regulation. If all nations do not harmonize carbon prices, then incomplete regulation will affect the types of goods produced and consumed. Leakage occurs when partial regulation results in an *increase* in emissions in unregulated parts of the economy.[6] The vertical targeting of the policy will affect the magnitude of leakage. Here, leakage could be an issue with either upstream or downstream regulation.

Define the market demand for a good as $Q^D(p)$. We can write the residual demand for regulated firms' output as $Q^{DR}(p) = Q^D(p) - Q^{SU}(p)$, where Q^{SU} represents the supply of firms not regulated. In particular, Q^{SU} will include output from foreign firms. Note that not all foreign production need be unregulated, as firms in some countries already face a carbon price. In addition, many policy proposals include a discussion of border adjustments (for example, see Metcalf and Weisbach 2009). Fischer and Fox (2009) compare the effects on leakage of border taxes versus rebates.

Decomposing market demand into its two components—$Q^{DR}(p)$ and $Q^{SU}(p)$—is useful in understanding the relationship between leakage and vertical targeting. In particular, if market prices increase in equilibrium, residual demand for domestic firms will fall for two reasons. Consumers buy less, which reduces emissions, but also foreign firms produce more, which will increase emissions. These unregulated emissions cause damage. If marginal damages are (locally) constant and equal the carbon price τ, then regulating segment v will result in additional damages (AddDmg):

$$\text{AddDmg}_v = \tau \bar{F} \bar{r} [Q^{SU}(p_1) - Q^{SU}(p_0)], \tag{11}$$

where $\bar{F}$ and $\bar{r}$ represent unregulated firms' fuel carbon content and end-of-pipe emissions rate, and p_1 and p_0 denote the price of good ν 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.

This also applies to a multiproduct setting. When close substitutes, more leakage occurs in markets for unregulated goods. In general, more precisely defined markets will have greater substitutes, so fine-tuned regulations may cause greater leakage. Note that this perspective has focused narrowly on the prices of the regulated good. In a general equilibrium setting, prices throughout the vertical chain, and in the rest of the economy, will also be affected. As such, leakage could occur in many industries.

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[6] Many recent papers examine leakage. For example, Fowlie (2009) develops a theory of incomplete regulation. She shows how leakage can, in some cases, increase total emissions relative to no regulation, and in other cases, decrease emissions relative to full regulation. Bushnell and Chen (2009) simulate the Western US electricity grid to examine how various proposals on how permits are allocated would affect the degree of leakage.

One particular type of leakage deserves further examination. Reshuffling occurs when firms do not change production (firms' location, output, and methods stay fixed) but do change where they sell the goods. In electricity markets, reshuffling may occur if regulation requires LSEs to document the sources of purchased power (Bushnell, Peterman, and Wolfram 2008). Unlike leakage, where the location and amount of production of carbon-intensive goods physically changes, reshuffling looks more like an accounting exercise. Producers sell the relatively clean power to the regulated LSEs and the relatively dirty power to others. For goods where transportation is inherently difficult to track, like electricity, regulators may find reshuffling particularly problematic.

Regulators face the issue of reshuffling for other goods with heterogeneous carbon intensities. Within biofuels, for example, some fuels have carbon rates well below that of oil, while others may exceed crude's carbon content. Even with consumer goods, heterogeneity arises due to production technology differences. Suppose that an import tariff were enacted, and regulators could accurately measure the carbon content of the imported goods. We would expect that some reshuffling would take place with only the clean goods coming to the United States and the dirty goods staying in the other country. Unlike with leakage, emissions may not increase with reshuffling.[7] However, import tariffs will only apply to the cleanest goods in equilibrium, limiting their effectiveness in *reducing* emissions.

11.3.3 Offsets

If regulators decide to use upstream regulation, they may consider giving firms credit for choosing options that reduce GHGs downstream. Regulators offer offset programs to lower overall abatement costs while still reducing emissions to a set level (i.e., the cap). However, asymmetric information may cause unintended consequences.

Suppose that regulators have imperfect information regarding how much firms would emit without regulation (i.e., the baseline). Define $\overline{e} \equiv \overline{qFr}$ as regulators' expected baseline. Firms have private information; they know the actual unregulated emissions e^0. After opting in, regulators and firms observe actual emissions $e \equiv qFr$. Finally, I denote actual abatement as $\alpha \equiv e^0 - e$ and regulators' expected abatement as $\overline{\alpha} \equiv \overline{e} - e$.

The objective function for firms facing input-based regulation with offsets is:

$$(12) \qquad \max_{q,F,r} \pi = P(Q)q - c(q) - t_{\text{in}}Fq - a_{\text{in}}(q,F) - a_{\text{out}}(q,F,r) + \sigma(r,\overline{e}).$$

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[7] If firms reshuffle through electronic transfers, then emissions will not increase. On the other hand, if reshuffling requires that goods be physically moved to different locations, this would (presumably) increase emissions due to additional transportation.

The subsidy σ commonly takes the form of pollution credits for perceived abatement $\bar{\alpha}$. Regulated firms can use offset credits in lieu of using pollution permits and, thus, equal the carbon price in equilibrium: $\sigma(r,\bar{e}) = t_{\text{in}}\bar{\alpha}$.

Asymmetric information over α can result in adverse selection (Montero 1999). Unlike with an end-of-pipe regulation, firms have a choice to opt into an offset program. For a continuous, differentiable abatement technology, a firm will opt in if the marginal subsidy exceeds the marginal abatement costs, $\partial\sigma/\partial r > \partial a_{\text{out}}/\partial r$. If marginal abatement costs lie below the carbon price t_{in}, then such adoption could lower total abatement costs across all firms.

Regulators will likely either understate or overstate baseline emissions e^0, and *both* cases may lead to adverse effects. First, if $\bar{e}$ falls substantially below e^0, then a firm with low marginal abatement costs may lack the incentive to reduce r. Even though the firm could reduce emissions at low social costs, the subsidy would be insufficient to provide it with incentives to do so. This type of error will result in forgone cost savings to society. However, these opportunities would also be missed in an input-based regulation without offsets.

The second type of error could actually increase social costs relative to a no-offset regime. In this case, a particularly lucrative subsidy may entice even a firm with high marginal abatement costs to opt in. This will occur if the regulator substantially overstates the baseline emissions, $\bar{e} > e^0$. Given continuous and differentiable abatement costs, a firm could abate just a small amount, $|\Delta r| < \varepsilon$, and receive a large subsidy. The number of credits awarded equal the *perceived* abatement, $\bar{\alpha} > 0$, even though actual abatement α is near zero. In this case, when virtually no actual abatement occurs, society incurs no costs (even those firms receive transfers).

However, for "lumpy" investments, this type of error can result in costs to society. Lumpiness may result from a technological characteristic (CCS may have large capital costs and low marginal costs) or a policy (if regulators can only monitor large changes in r). In either case, firms must now either make a large investment or none at all.

Offsets provide net benefits to society equal to the actual value created (i.e., the carbon price times actual abatement) less the firms' abatement costs: $t_{\text{in}}\,\alpha - a_{\text{out}}$. Under a cost-effective policy, firms abate only if the social benefits exceed social costs. If $e^0 = \bar{e}$, offsets would be cost-effective. However, firms with larger predicted baselines, $\bar{e} > e^0$, may have incentive to abate even if doing so reduces social welfare. Even with unbiased estimates, measurement error in the regulators' perceived baseline results in higher costs due to adverse selection. To see this, note that a firm will opt in only if it receives payments greater than cost, $t_{\text{in}}\bar{\alpha} > a_{\text{out}}$. Thus, offsets increase abatement costs when firms have incentive to opt in ($t_{\text{in}}\bar{\alpha} > a_{\text{out}}$) even though doing so results in a net loss to society ($t_{\text{in}}\alpha < a_{\text{out}}$), or:

$$t_{\text{in}}\bar{\alpha} > a_{\text{out}} > t_{\text{in}}\alpha. \tag{13}$$

Some high-cost firms will opt in, and some low-cost firms will opt out.[8]

Furthermore, offsets can result in a form of leakage.[9] If firms abate α but earn credits for $\bar{\alpha}$, then overall emissions increase by $\bar{\alpha} - \alpha$. These additional emissions increase the damages associated with climate change. If damages are locally linear and, if marginal damages equal the carbon price, then these additional emissions cost society $t_{\text{in}} \cdot (\bar{\alpha} - \alpha)$.

Combining the net benefits from offsets with the damages from additional emissions, one can measure the overall net losses from offsets (OffLoss) across all firms in link v as:

$$\text{(14)} \qquad \text{OffLoss} = \sum_{i=1}^{1} \{[-(t_{\text{in}}\alpha - a_{\text{out}}) + t_{\text{in}} \cdot (\bar{\alpha} - \alpha)] \cdot \mathbf{1}[t_{\text{in}}\bar{\alpha} > a_{\text{out}}]\},$$

where $\mathbf{1}[\cdot]$ indicates opting in. Note that OffLoss may be positive or negative.

While regulators cannot observe e^0 for each firm, they may know its distribution. In this case, the expected net losses from offsets, $E[\text{OffLoss}_v]$, can help determine the least costly policy. Combining all four components—cost-effectiveness, transactions costs, leakage, and offsets—the link v^{**} minimizes total social costs:

$$\text{(15)} \qquad v^{**} = \arg \min_{v \in \{1 \ldots, V\}} \{\text{AddCost}_v + l_v \kappa + \text{AddDmg}_v + E[\text{OffLoss}_v]\}.$$

11.4 Other Issues of Vertical Targeting

Next, I briefly discuss several other issues that have been raised in the context of upstream versus downstream regulation. These include imperfect competition, regulatory treatment, tax salience, and integrating markets.

11.4.1 Imperfect Competition

With regard to upstream regulation, some raise a concern that imperfect competition amplifies carbon price pass-through. In particular, some argue that input-based carbon prices will be marked up repeatedly in a chain of industries with market power. In contrast, they posit, a downstream carbon price will only affect the last segment of the chain.

Consider three issues regarding imperfect competition and carbon price pass-through. First, while firms with market power have incentives to increase prices above marginal costs, this does not imply that an additional carbon cost will increase market prices by more than the additional cost. Firms optimize by setting marginal revenue equal to marginal costs, and the slope of marginal revenue may be either greater or less than the slope of

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8. Note that these distortions can persist in the long run as the subsidy reduces the permit price below the cost-effective price τ_{out}.

9. This occurs only if regulators tie the offset program to the cap-and-trade regulation. However, if separate government subsidies or voluntary markets fund offsets and regulated firms cannot use these offsets for compliance, then the additional supply of offsets will not reduce abatement in the regulated market.

inverse demand. Second, when firms exert market power, the theory of the second best applies, and the optimal tax need not equal marginal damages (see, for example, Buchanan 1969). Third, with fixed proportions (whereby firms cannot substitute other inputs to change emissions, that is, $\bar{r} = r$), upstream and downstream regulation will result in the same equilibrium. Chiu, Mansley, and Morgan (1998) refer to this as the irrelevance result.

To see this last point, I use an example of a chain of imperfectly competitive industries. In particular, suppose that a monopolist in one market sells to another downstream monopolist, who then sells to customers. The upstream firm maximizes profits (π_u) by producing q_u at an input price w. The upstream firm incurs costs $c(q_u)$. The downstream firm maximizes profits (π_d) by producing q_d, for which consumers pay p. The downstream firm pays $wq_u + k(q_d)$. Using notation from the previous sections, the regulator will impose either an input-based or an end-of-pipe carbon price. The resulting profit functions equal:

$$\pi_u = w(q_u)q_u - c(q_u) - t_{\text{in}}\bar{r}Fq_d$$

$$\pi_d = p(q_d)q_d - wq_u - k(q_d) - \tau_{\text{out}}\, rFq_d.$$

For simplicity, let $q_d = q_u$ and $F = 1$. I write the firms' first order conditions as:

$$w + w'q = c' + t_{\text{in}}\bar{r}$$

$$p + p'q = w + k' + \tau_{\text{out}}r,$$

or, rearranging terms, the downstream firm's response function as $w = p + p'q - k' - \tau_{\text{out}}\, r$. Thus, solving backward, the upstream firm's first-order condition becomes:

$$p + 3\,p'q + p''q^2 - c' - k' - k''q = t_{\text{in}}\bar{r} + \tau_{\text{out}}r.$$

Note that if $r = \bar{r}$, then an upstream carbon price equates to downstream policy.[10]

11.4.2 Regulation

Metcalf and Weisbach (2009) discuss how regulated industries may treat upstream and downstream policies differentially. For example, if electric utilities face direct, end-of-pipe regulation and receive grandfathered permits, then regulators may limit their ability to pass on marginal cost increases: the opportunity cost of permits in hand may not be treated the same as a purchased permits. In contrast, the same utility may easily pass on higher input prices under upstream regulation. Note that from a social welfare perspective, fully incorporating increases in marginal costs in deter-

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[10] For perfectly competitive downstream markets, firms' first-order condition imply $w = p - k' - \tau_{\text{out}}r$. The upstream monopolist maximizes profits by solving $p + p'q - c' - k' - k''q = t_{\text{in}}\bar{r} + \tau_{\text{out}}r$. Again, the policies are equivalent. Chiu, Mansley, and Morgan (1998) reach the same conclusion for an upstream monopolist selling to downstream Cournot oligopolists.

mining the market equilibrium price will be efficient. Namely, the optimal price would be where marginal social costs equal marginal social benefits, not where price equals average costs.

11.4.3 Tax Salience

Some promote downstream regulation by arguing that a carbon price near the point of emissions (e.g., power plants or gasoline stations) will make the policy more salient for the polluter and, therefore, result in greater response. This argument stems from findings of behavioral economists, who posit that consumers respond more to easily computed taxes. Chetty, Looney, and Kroft (2009) look at state-level alcohol consumption from 1970 to 2003. They find a greater change in consumption with taxes already included in the shelf price (excise taxes) than with taxes applied at the point of sale (sales taxes). Consumers find those taxes already imbedded in the price of the good to be the most salient. Note that these findings suggest that *any* policy in which firms account for carbon costs in the "shelf" price (whether it be because of an increase in fuel prices from input-based regulation or because of an increase in marginal costs directly from an end-of-pipe regulation) would be more effective at changing end users' behavior than a carbon price placed on consumers afterward.

11.4.4 Integrating Markets

The optimal vertical segment of regulation for one emissions source's vertical chain may differ across sources. For example, regulating refineries may minimize costs in the case of vehicles' carbon, while emission source regulation may minimize costs for stationary facilities.

In integrating these different regulations, it will be important, from a cost-effective perspective, that chains do not "cross." Namely, cost-effectiveness will fail if firms pay the carbon price more than once: for example, if a refinery faces a carbon price and then sells its fuel oil to a power plant already paying for emissions, then the outcome will not be least cost. On the other hand, in integrating regulations across markets, establishing trading ratios so that refineries and power plants can trade permits (in dollars per ton of carbon dioxide, for example) will enable greater gains and lower overall costs. If power plants can reduce emissions at a lower marginal cost than can a refinery, then allowing firms to trade across sectors will lower overall costs.

11.5 Conclusions

This chapter sets out some key issues in deciding what level of a vertical chain of industries to target in designing regulation. After developing a model of cost-effectiveness, the chapter examines several reasons why potential gains from trade may not be realized. First, upstream regulation could substantially reduce transactions costs. Regulating a few thousand fossil-fuel producing companies would account for 80 percent of GHG emissions (Metcalf and Weisbach 2009). Second, 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. Third, 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 (Montero 1999). This chapter discusses how cost-effectiveness, transactions costs, leakage, and offsets relate to the issue of regulatory vertical segment selection.

References

Buchanan, James. 1969. "External Diseconomies, Corrective Taxes, and Market Structure." *American Economic Review* 59 (1): 174–77.

Burrows, Paul. 1977. "Pollution Control with Variable Production Processes." *Journal of Public Economics* 8:357–67.

Bushnell, James, and Yihsu Chen. 2009. "Regulation, Allocation, and Leakage in Cap-and-Trade Markets for CO_2." NBER Working Paper no. 15495. Cambridge, MA: National Bureau of Economic Research.

Bushnell, James, Carla Peterman, and Catherine Wolfram. 2008. "Local Solutions to Global Problems: Climate Change Policies and Regulatory Jurisdiction." *Review of Environmental Economics and Policy* 2 (2): 175–93.

Carlton, Dennis W., and Glenn C. Loury. 1980. "The Limitations of Pigouvian Taxes as a Long-Run Remedy for Externalities." *Quarterly Journal of Economics* 95 (3): 559–66.

Chetty, Raj, Adam Looney, and Kory Kroft. 2009. "Salience and Taxation: Theory and Evidence." *American Economic Review* 99 (4): 1145–77.

Chiu, Stephen, Edward C. Mansley, and John Morgan. 1998. "Choosing the Right Battlefield for the War on Drugs: An Irrelevance Result." *Economics Letters* 59 (1): 107–11.

Fischer, Carolyn, and Alan K. Fox. 2009. "Comparing Policies to Combat Emissions Leakage: Border Tax Adjustments versus Rebates." RFF Discussion Paper no. 2009-02. Washington, DC: Resources for the Future.

Fowlie, Meredith. 2009. "Incomplete Environmental Regulation, Imperfect Competition, and Emissions Leakage." *American Economic Journal: Economic Policy* 1 (2): 72–112.

Fullerton, Don, and Ann Wolverton. 2000. "Two Generalizations of a Depost-Refund System." *American Economic Review: Papers and Proceedings* 90 (2): 238–42.

Metcalf, Gilbert, and David Weisbach. 2009. "The Design of a Carbon Tax." *Harvard Environmental Law Review* 33 (2): 499–556.

Montero, Juan-Pablo. 1999. "Voluntary Compliance with Market-Based Environmental Policy: Evidence from the US Acid Rain Program." *Journal of Political Economy* 107:998–1033.

Schmalensee, Richard. 1976. "Another Look at the Social Valuation of Input Price Changes." *American Economic Review* 66 (1): 239–43.

Smith, V. Kerry. 1992. "Environmental Costing for Agriculture: Will It Be Standard Fare in the Farm Bill of 2000?" *American Journal of Agricultural Economics* 74 (5): 1076–88.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. 2007. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.* Accessed April 12, 2010. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html.

United States Census Bureau. 2010. *Quarterly Census of Employment and Wages.* Accessed April 10, 2010. http://www.bls.gov/iag/tgs/iag447.htm.

United States Department of Transportation. 2009. "State Motor-Vehicle Registrations—2008." http://www.fhwa.dot.gov/policyinformation/statistics/2008/pdf/mv1.pdf.

United States Energy Information Administration. 2008. *Annual Energy Review.* DOE/EIA-0384. Accessed April 10, 2010. http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf.

Comment

Roberton C. Williams III

Erin Mansur's chapter provides a concise, clear, and thorough description of the trade-offs between upstream and downstream regulation of an environmental externality, with a particular focus on regulation of greenhouse gases (GHGs). In my comments, I will begin with a brief summary of the chapter's main points and then will go on to describe one additional potentially important factor to consider and to provide further discussion of the immediate policy implications of these points for climate policy.

The comparison of upstream and downstream regulation is often presented as a dichotomous choice, but the chapter points out that there are many different stages in the production process that could be regulated. Nonetheless, the terms are still useful: "upstream" refers to regulation closer to the beginning of the value chain (the stage where polluting inputs first enter the economy) and "downstream" refers to regulation closer to the end of the chain (where consumers use polluting goods).

Regulation provides the most efficient incentives to reduce emissions when it is targeted at the stage where those emissions occur. Regulating upstream of this point provides less efficient incentives. There may be ways to reduce use of a polluting input without actually reducing emissions at all (perhaps by switching from a regulated polluting input to an unregulated but equally

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Roberton C. Williams III is associate professor of agricultural and resource economics at the University of Maryland, a senior fellow of Resources for the Future, and a research associate of the National Bureau of Economic Research.

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