Upstream versus Downstream Implementation of Climate Policy

Erin T. Mansur*

May 10, 2010

Abstract

This chapter examines the tradeoffs of regulating upstream (*e.g.,* coal, natural gas, and refined petroleum product producers) versus regulating downstream (*e.g.,* direct sources of greenhouse gases (GHG)). In general, regulating at the source provides polluters with incentives to choose among more opportunities to abate pollution. This chapter develops a simple theoretical model that shows why this added flexibility achieves the lowest overall costs. The theory is then broadened to incorporate several reasons why these potential gains from trade may not be realized–transactions costs, leakage, and offsets–in the context of selecting the vertical segment of regulation.

This chapter examines the tradeoffs of regulating greenhouse gases (GHG) upstream versus downstream. Upstream regulation is typically thought of as focusing on firms that either produce or import 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 below: cost effectiveness, transactions costs, leakage, and offsets.

Before examining these issues, it is important to explore the terms "upstream" versus "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*. For some industries, the chain is relatively short while for others there are many links.

*Associate Professor, Yale School of Management and NBER, 135 Prospect Street, P.O. Box 208200, New Haven, CT 06520-8200, Tel: (203) 432-6233, Fax: (203) 432-6974, erin.mansur@yale.edu. I thank Severin Borenstein, Jim Bushnell, and Chris Snyder for useful comments on this chapter.

For example, consider the regulation of carbon dioxide (CO_2) emissions from personal vehicles. Figure 1 plots the vertical chain. The chain begins with the exploration and extraction of crude oil all over the world. Most likely, the oil that is used for transportation in the United States is extracted internationally. The US only produces a third of the oil that it consumes (Energy Information Administration (EIA), 2008). The second part of the vertical chain is the transportation of the crude oil, which is typically sent by pipeline, tanker, or both. Third, the oil reaches a refinery, most likely one of the 150 refineries in the US. Approximately 12 percent of motor gasoline consumed in the US is imported (EIA, 2008). Fourth, after refining the crude oil into motor gasoline, the product is moved typically by pipeline to one of about 390 major wholesale racks.[1] Fifth, it is then moved by truck to one of about 105,000 gasoline stations in the US (Census, 2010). Sixth, the gasoline is then purchased and pumped into one of the 244 million private or commercial registered motor vehicles in the US (Department of Transportation, 2009). While CO_2 emissions are released in each of the six links, the vast majority occurs during consumption of the final product in this case.

This example can be used to illustrate a couple of points regarding vertical targeting. First, the number of firms or consumers involved in each step may differ dramatically. As discussed below, regulating at the source of pollution is optimal in theory, assuming an otherwise functioning market. However, the number of firms owning the 150 US refineries plus those importing finished refined product into this country is *much* smaller than the number of registered vehicles. If there are few opportunities 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 definitions of "upstream" and "downstream" are unclear. The upstream industry could mean any one of several industries. In this example, upstream is typically considered refineries and downstream is thought of as vehicles. However, there are many

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

other choices. In other contexts, "upstream" might mean the polluters and "downstream" might mean consumers. For example, in electricity markets, upstream refers to regulating the sources of pollution, *i.e.*, the power plants, while downstream refers to regulating the purchases of 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. For this chapter, what is most relevant is understanding: (*i*) why, in a general setting, regulating polluters directly is expected to maximize social welfare, and (*ii*) why this might not be the case for carbon policy.[2] In particular, if regulating polluters is sub-optimal, would a regulation that is upstream *relative* to the source of pollution be more cost effective, or would one that is relatively downstream improve costs?

Theory of Cost Effectiveness

In most policy choice discussions—whether it be command-and-control regulation versus incentive-based regulation, or taxes versus tradeable permits—economists typically ask: which policy is more efficient, and which is relatively cost effective? 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 that is emitted):

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

[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.

[3]While this section examines cost effectiveness, the two questions are interrelated. In addition to the welfare effects from differences in costs, policies regulating different vertical segments may have additional welfare effects through allocative efficiency. Namely, if a cap-and-trade system is in place, cost inefficiencies will result a higher permit price. This will distort consumer behavior relative to a first-best solution. Furthermore, if the polluting industries are not perfectly competitive but for carbon regulation, then distorting output in these markets may either reduce or increase other welfare losses in society. This is the case if there are any other market distortions like market power, average-cost pricing, other externalities, *etc.*

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

Suppose that $a(q, F, r)$ can be separated into two additive components: $a_{in}(q, F)$, which is only a function of inputs, and $a_{out}(q, F, r)$, which is "end-of-pipe " technologies. Switching to a lower carbon fuel would be in a_{in}. For example, a vehicle switching from oil-based diesel to biodiesel, or a power plant switching from coal to natural gas. Other technologies like installing carbon capture and sequestration (CCS) technology on a power plant, which is literally end of pipe, would be in a_{out}. However, end-of-pipe technologies would also include 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 output-based, or end-of-pipe, regulation τ_{out}. We can rewrite the firm's objective function in equation (1) as:

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

where $\overline{r}$ is the emissions rate corresponding to the firm's unregulated fuel choice. As mentioned above, an unregulated firm would not abate, $\overline{r} = 1$. In this setting, the firm's first order conditions can be written as:

$$q \;:\; t_{in}F + \tau_{out}Fr = MR - c'(q) - \partial a_{in}/\partial q - \partial a_{out}/\partial q, \tag{3}$$

$$F \;:\; t_{in}q + \tau_{out}rq = -\partial a_{in}/\partial F - \partial a_{out}/\partial F, \tag{4}$$

$$r \;:\; \tau_{out}Fq = -\partial a_{out}/\partial r. \tag{5}$$

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. If this is feasible, like in the case of power plants that have Continuous Emissions Monitoring System (CEMS) in place, firms will be able to choose among all possible ways of reducing carbon. To enact this, regulators would set $t_{in} = 0$ and, if socially optimal, $\tau_{out} = MD$ where MD is 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):

$$\tau_{out} = MAC_{out} = \frac{MR - c'(q) - \frac{\partial a_{in}}{\partial q} - \frac{\partial a_{out}}{\partial q}}{Fr} = -\frac{\frac{\partial a_{in}}{\partial F} + \frac{\partial a_{out}}{\partial F}}{rq} = -\frac{\partial a_{out}/\partial r}{Fq}. \tag{6}$$

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

In contrast, an input-based regulation would set $\tau_{out} = 0$ and, in order to be allocatively efficient, $t_{in} = MD$. In this case, from equation (5) we see that firms have no incentive to abate using end-of-pipe technologies. Furthermore, the marginal abatement cost from reducing output or changing inputs depend on 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:

$$t_{in} = MAC_{in} = \frac{MR - c'(q) - \frac{\partial a_{in}}{\partial q} - \frac{\partial a_{out}}{\partial q}}{F} = -\frac{\frac{\partial a_{in}}{\partial F} + \frac{\partial a_{out}}{\partial F}}{q}. \tag{7}$$

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 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 2 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 2 shows this in a slightly different way. The horizontal axis is the overall

[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 is τ_{out}.

amount of abatement required, aggregating over all polluters, by the policy $\widehat{A}$. The left vertical axis is for the input-based MAC_{in}, which is based on equation (7). The right vertical axis is for the end-of-pipe MAC_{end}, which are all incentives to abate that are in MAC_{out} from equation (6) but not in equation (7). In other words, MAC_{end} includes all the abatement options resulting from changing r. The least cost option is at the point A^* where the marginal costs equate, $MAC_{in} = MAC_{end}$. The shaded area shows the additional costs ($AddCost$) that firms incur by only being rewarded for changing q and F:

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

Under the theoretical assumptions above, flexibility achieves the lowest overall costs. As a starting point then, downstream regulation is arguably the more cost effective policy. Furthermore, there may be future innovations in end-of-pipe technologies that firms would have incentives to develop and invest in if the carbon price were on output that they would not have incentive to do if facing an input-based policy. However, there are several reasons why these potential gains from trade would not be realized, which this chapter now addresses.

Transactions Costs

A major hurtle for establishing an end-of-pipe regulation is the cost of monitoring and enforcing regulation for millions of pollution sources. In contrast, a regulation that focused upstream of the pollution source could substantially reduce 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 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.

I modify the theory from the previous section to account for these costs. Suppose that regulators incur a cost κ in determining *each* polluter's emissions rate r. In addition, monitoring the usage and carbon content of each fuel also results in costs. For simplicity, assume that these are also κ but are incurred for each supplier of an input. Furthermore, assume that the decision to regulate upstream or downstream–*i.e.,* 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, there may be many segments in the vertical chain that could be regulated. In order to minimize overall costs, regulators may consider all V options, where V is the number of vertical links associated with carbon emissions from one particular sector or industry. The least cost option, that still meets an emissions cap, now is v^*:

$$v^* = \arg \min_{v \in \{1,..,V\}} \{AddCost_v + l_v \kappa\}, \tag{9}$$

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

In general, moving further upstream (or downstream) from the source of pollution results in forgoing some abatement opportunities. Hence, *AddCost* is expected in increase monotonically with vertical distance from the pollution source. However, the number of firms to be regulated is not necessarily monotonically decreasing as one goes further upstream. In the vehicle example, while there are many more vehicles than refineries, there are also more firms extracting oil worldwide than there are firms that own refineries in the US.

Finally, it is important to note that transactions costs are a function of technology. In the future, technology will likely improve making collecting and using information even easier. As a result, the cost of regulating more complex vertical levels will likely fall; regulating 250 million vehicles may be feasible at some point. In other words, the optimal vertical targeting of regulation may change over time.

Leakage

A second major concern of upstream versus downstream regulation is leakage. 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.[5] The vertical targeting of the policy will affect the magnitude of leakage. Here, there are reasons why leakage could be an issue with either upstream or downstream regulation.

The market demand for a good is $Q^D(P)$. We can write the residual demand for regulated firms' output as: $\widetilde{Q}^{DR}(P) = Q^D(P) - Q^{SU}(P)$, where Q^{SU} is 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 of border taxes versus rebates on leakage.

Decomposing market demand into its two components–$\widetilde{Q}^{DR}(P)$ 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 additional emissions cause damage as they are unregulated. If marginal damages are (locally) constant and equal the carbon price τ, then regulating chain v will result in additional damages ($AddDmg$):

$$AddDmg_v = \tau \int_{P_0}^{P_1} Q^{SU}(p) Frdp, \tag{10}$$

where P_1 and P_0 are the prices of the v good 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. If unregulated goods are close substitutes, leakage is more likely to occur. In general, the more precisely defined is a market, the greater the number of substitutes. Combining equations (10) and (9), the policy v^{**} minimizes total social costs, including leakage and transactions

[5] Many recent papers examine leakage. For example, Fowlie (2009) developes 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.

costs:

$$v^{**} = \arg \min_{v \in \{1,..,V\}} \{AddCost_v + l_v \kappa + AddDmg_v\} . \tag{11}$$

One particular type of leakage is reshuffling. Bushnell, Peterman, and Wolfram (2008) examine reshuffling in energy markets. In electricity markets, downstream regulation is on LSEs purchasing power. Unlike leakage where the location and amount of production of carbon-intensive goods physically changes, reshuffling is more like an accounting exercise. Producers sell the relatively clean power to the regulated LSEs and the relatively dirty power to others. This is particularly an issue for electricity where tracking electrons is difficult.

However, even for other goods with heterogeneous carbon intensities, reshuffling may be an issue. For example, within biofuels there are some fuels that have carbon rates well below that of oil while others are even above oil. Even with consumer goods there will be heterogeneity due to differences in production technologies. 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 US and the dirty goods staying in the other country. Unlike with leakage, emissions may not increase with reshuffling.[6] However, the effectiveness of *reducing* emissions by using an import tariff is limited as it will only be applied to the cleanest goods that are imported.

Offsets

The final issue that arises is that of offsets. If regulators decide to use upstream regulation, they may consider giving firms credit for choosing options that reduce GHGs downstream. The intent of these offset programs is to lower overall abatement costs while still reducing emissions to a set level (*i.e.*, the cap). However, there may be unintended consequences due to asymmetric information.

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.

[6] If reshuffling is just though electronic transfers, then there will not be additional emissions. On the other hand, if the goods need to be physically moved to different locations, this would (presumably) increase emissions due to additional transportation.

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:

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

The subsidy for reducing the emissions rate, σ, is commonly in the form of pollution credits for perceived abatement $\overline{\alpha}$. These offset credits can be used by regulated firms in lieu of using pollution permits. As such, they are valued at the carbon price in equilibrium. Hence, $\sigma(r,\overline{e}) = t_{in}\overline{\alpha}$.

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, $\partial\sigma/\partial r > \partial a_{out}/\partial r$. If marginal abatement costs are low relative to the (input-based) carbon price t_{in}, then such adoption could lower total abatement costs across all firms.

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

The second type of error could actually increase costs relative to a no offset regime. In this case, a firm with high marginal abatement costs may opt in if the subsidy is particularly lucrative. This will occur if the regulator substantially overstates the baseline emissions, $\overline{e} > e^0$. If the abatement costs are continuous and differentiable, then 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, $\overline{\alpha} > 0$, even though actual abatement α is near zero.

This second type of error can be much more costly if investments are "lumpy." Lumpiness may be the result of a technological characteristic (CCS may have large capital costs and low marginal costs), or a function of policy (regulators may be able only to 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: $t_{in}\alpha - a_{out}$. Cost-effectiveness implies that firms abate if and only if the net benefits are positive. If $e^0 = \overline{e}$, offsets would be cost effective. However, firms with larger predicted baselines, $\overline{e} > e^0$, will have added incentives to abate and vice versa. Even if regulators' baseline estimates were unbiased, measurement error would still result in higher costs due to adverse selection.

To see this, note that a firm will opt in only if it receives a payment that is greater than its cost, $t_{in}\overline{\alpha} > a_{out}$. Thus, a firm may opt in even though its has net losses to society if $t_{in}\overline{\alpha} > a_{out} > t_{in}\alpha$. Some high-cost firms with opt in, and some low-cost firms will opt out.

Furthermore, offsets can result in a form of leakage.[7] If firms abate α but are given credits for $\overline{\alpha}$, then overall emissions increase by $\overline{\alpha} - \alpha$. Assuming that marginal damages equal the carbon price, these additional emissions cost society $t_{in} \cdot (\overline{\alpha} - \alpha)$.

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:

$$OffLoss_v = \sum_{i=1}^{l} \left\{ \left[-(t_{in}\alpha - a_{out}) + t_{in} \cdot (\overline{\alpha} - \alpha) \right] \cdot \mathbf{1} \left[t_{in}\overline{\alpha} > a_{out} \right] \right\}, \tag{13}$$

where $\mathbf{1}[\cdot]$ is an indicator variable of opting in. Note that $OffLoss$ may be positive or negative.

While regulators cannot observe e^0 for each firm, they may be know its distribution. If this the case, then determining the expected net losses from offsets, $E[OffLoss_v]$, may be helpful in determining the least costly policy. Combining all four components–cost effectiveness, transactions costs, leakage, and offsets–the link that minimizes total social costs is v^{***}:

$$v^{***} = \arg \min_{v \in \{1,..,V\}} \left\{ AddCost_v + l_v\kappa + AddDmg_v + E[OffLoss_v] \right\}. \tag{14}$$

[7] This will not occur if the offset program is solely funded by government subsidies. In other words, the credits cannot be used by firms to offset regulated pollution.

Integrating Markets

The optimal vertical segment of regulation for one emissions source's vertical chain may not be the optimal one for another source's chain. For example, it may be the case that the social costs associated with vehicles are minimized by regulating either refineries or oil wells. For stationary sources, regulation closer to the actual source of emissions may be feasible and least costly.

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 carbon is priced multiple times: for example, if a refinery faces a carbon price and then it sells its fuel oil to a power plant that is also regulated by a carbon price, then the outcome with 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.

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 will depend on whether firms are regulated 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 these four important ideas–cost effectiveness, transactions costs, leakage, and offsets–as they relate to the issue of regulatory vertical segment selection.

References

[1] Bushnell, James and Yihsu Chen. 2009. "Regulation, Allocation, and Leakage in Cap-and-Trade Markets for CO_2," NBER Working Paper 15495.

[2] 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): 175-193.

[3] Fischer, Carolyn and Alan K. Fox (2009) "Comparing Policies to Combat Emissions Leakage: Border Tax Adjustments versus Rebates," RFF Discussion Paper 2009-02.

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

[5] Hobbs, Benjamin F., James Bushnell, and Frank A. Wolak. 2010. "Upstream vs. Downstream CO_2 Trading: A Comparison for the Electricity Context," Energy Institute at Haas Working Paper 203.

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

[7] 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.

[8] 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.* http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html (accessed April 12, 2010).

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

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

Tables and Figures

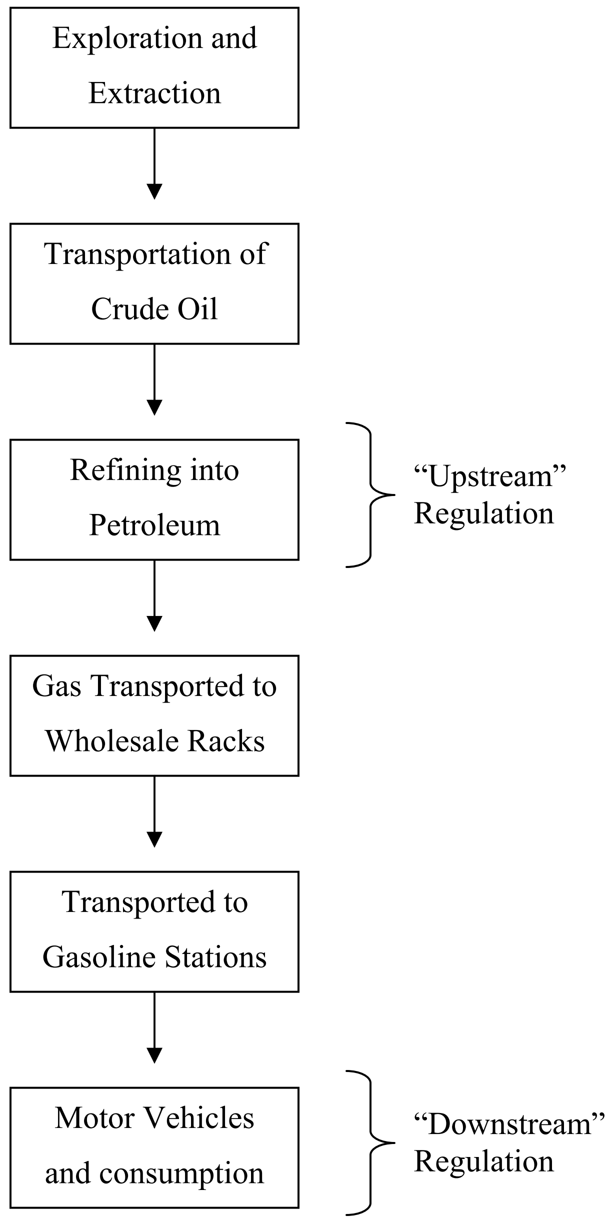

Figure 1: Vertical Chain of Carbon Dioxide Emissions from Motor Vehicles

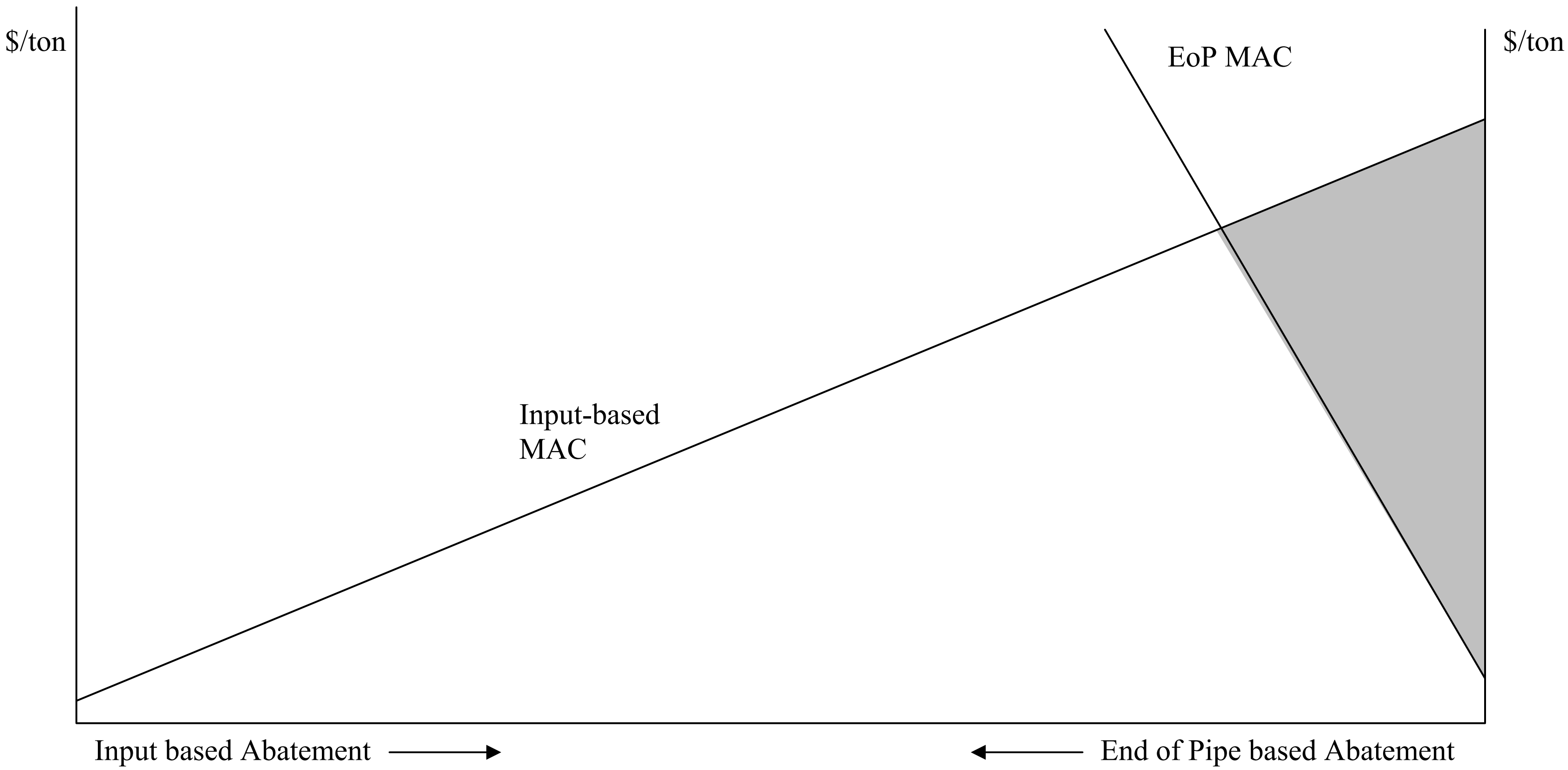

Figure 2: Depiction of Marginal Abatement Costs (MAC) broken into Input-based and other, End-of-Pipe (EoP) Abatement. The horizontal axis is the total amount of abatement required under the cap. The shaded area is the additional costs incurred by only allowing input-based abatement methods to be used.