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Vertical Targeting and Leakage in Carbon Policy

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In this paper, we examine the intersection between two important aspects of climate policy design. The first is the point of regulation. Should it be placed on pollution sources, carbon-rich inputs, or consumers? This issue of upstream versus downstream regulation is one that we will refer to as *vertical targeting*. The second aspect concerns the external effects of a local climate policy. *Leakage* occurs when partial regulation results in an increase in emissions in unregulated parts of the economy. This paper examines how regulators' choice of upstream versus downstream environmental regulation affects emissions in other countries with lax environmental regulation.

These two elements of climate policy are closely related. In many contexts, the selection of the point of regulation in the vertical chain is influenced, if not driven by, concerns over extra-jurisdictional impacts. Given the global nature of the pollutant, regulators in any specific jurisdiction need to be mindful of how local limits will effect global emissions. Regions imposing greenhouse gas restrictions may consume more than they produce of carbon-intensive goods, such as gasoline or cement. In such cases, regulations imposed on consumers can "reach" upstream to producers located outside the regulated areas. For example, by raising the cost of consuming carbon-intensive electricity in California, regulators in that state hope to reduce the combustion of coal in other regions of the western United States.

It is important to recognize that vertical targeting is but one mechanism through which regulators can combat leakage. Much academic research and legislation has focused on the legal and economic merits of "border adjustments," such as import tariffs based on carbon content, and also the "updating" of emissions credit allocations in a fashion that can subsidize domestic production.[1] These mechanisms can mitigate leakage effectively, although many legal and regulatory questions remain regarding their implementation within the confines of international trade agreements (Jeffrey Frankel 2008) or the Commerce Clause of the US Constitution. Vertical targeting can be viewed as an alternative to border adjustments that is less vulnerable to such conflicts.

In addition to leakage, vertical targeting has implications for cost effectiveness, transactions costs, and offsets. Direct regulation allows firms to achieve the lowest compliance costs: they may abate emissions by changing inputs, output levels, or end-of-pipe technology. However, the transactions costs of monitoring and enforcing regulation for millions of cars and buildings could dwarf the incremental benefits from direct regulation. Upstream regulation could substantially reduce these transactions costs (Gilbert Metcalf and David Weisbach 2009).[2] David Driesen and Amy Sinden (2009) promote Dirty Input Limits (i.e., upstream regulation) because of administrative costs and efficiency (being broader in scope). Mansur (forthcoming) discusses how upstream regulation may lead to

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[1] For example, Carolyn Fischer and Alan K. Fox (2009) compare the effects on leakage of border taxes versus rebates. Meredith L. Fowlie (2009) examines incomplete regulation with imperfect competition, and shows how leakage may increase total emissions relative to no regulation or, in other cases, may decrease emissions relative to full regulation. Recent empirical papers on leakage include Fowlie, Mar Reguant, and Stephen Ryan (2010) and Bushnell and Yihsu Chen (2009). In a broader context, the pollution havens hypothesis literature examines the interaction between environmental regulation and international trade (Bryan R. Copeland and M. Scott Taylor 2004).

[2] In particular, the authors show that regulating a few thousand fossil fuel producing companies would account for 80 percent of US greenhouse gas emissions. By including some select nonfossil polluters, an additional 10 percent of total emissions would be regulated with modest transactions costs.

more offsets, which have ambiguous effects on welfare.[3]

I. Vertical Targeting and Leakage

The interaction between vertical targeting and leakage can be complex. First, there are several points in the supply chain of interest, ranging from fundamental inputs such as fossil fuels to the production of intermediate products such as fertilizer or cement, to the consumption of the final product. In some cases the act of consumption can create significant emissions (e.g., gasoline), while in others the bulk of the emissions are created in the production of the product (e.g., cement).

Further, there can be great heterogeneity in the upstream or "life-cycle" carbon content of some otherwise identical commodities, such as electricity or ethanol. In such cases, regulating the downstream consumption of a product based upon its specific upstream carbon content can create incentives to manipulate those measurements (Benjamin Hobbs, Bushnell, and Frank Wolak 2010) as well as lead to the reshuffling of the pairings between production sources and consumers (Bushnell, Carla Peterman, and Catherine Wolfram 2008). For example, a US policy targeting purchases of oil from Canadian bituminous (e.g., "tar") sands due to its relatively carbon-intensive production process could lead to increased Canadian exports to Asia rather than a reduction in tar-sands production.

Here, we more explicitly model the various potential sources of carbon emissions throughout the supply chain. While we make some functional form assumptions for tractability, we try to capture the key elements of the problem in a general fashion. This allows us to examine dramatically different circumstances ranging from cases where the bulk of carbon emissions is far upstream to cases where emissions primarily occur during consumption. We can also examine cases where either domestic supply or demand may dominate the world market, as well as cases where domestic firms and consumers play a small role.

[3] In this case, 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 might allow society to achieve emissions reduction goals at a lower cost. However, offset programs could increase emissions due to adverse selection.

II. Model

Consider two international industries that are vertically related. These competitive markets are made up of four groups of firms: upstream foreign supply, S_u, upstream domestic supply, $\tilde{S}_u$, and the corresponding downstream supply, S_d and $\tilde{S}_d$, respectively. Downstream demand is similarly composed $(D_d, \tilde{D}_d)$, while world upstream demand (Q_u^D) is derived from the downstream market. For downstream and upstream prices P_d and P_u, the equilibrium is where: $P_d = f_1(D_d) = f_2(\tilde{D}_d) = f_3(S_d) + \beta P_u = f_4(\tilde{S}_d) + \tilde{\beta} P_u$, and $P_u = f_5(Q_u^D) = f_6(S_u) = f_7(\tilde{S}_u)$. This assumes downstream firms use the carbon-intensive input in fixed proportions, β and $\tilde{\beta}$.

For simplicity, we assume that β, $\tilde{\beta}$, and the emissions rates r_j for source j (i.e., foreign and domestic firms and consumers) are held fixed: abatement is only through output decisions. Domestic regulators may target any domestic entity $(\tilde{S}_u, \tilde{S}_d, \tilde{D}_u, \tilde{D}_d)$ with corresponding carbon prices τ_u^S, τ_d^S, τ_u^D, and τ_d^D. However, as domestic upstream demand is imbedded in the downstream supply decision, τ_u^D is redundant. We assume that there are neither international emissions policies nor boarder adjustments.

This paper asks: how does leakage, namely foreign emissions from source $j(E_j)$, change with domestic policy $i(\partial E_j / \partial \tau_i)$? With these carbon prices, the equilibrium is

$$(1) \qquad \begin{aligned} P_d &= f_1(D_d) = f_2(\tilde{D}_d) - \tau_d^D \\ &= f_3(S_d) + \beta P_u \\ &= f_4(\tilde{S}_d) + \tilde{\beta} P_u + \tau_d^S, \\ P_u &= f_5(Q_u^D) = f_6(S_u) \\ &= f_7(\tilde{S}_u) + \tau_u^S, \end{aligned}$$

where prices are for foreign producers and consumers. We show that these policies' effects on leakage depend on: (i) whether the policy is placed directly on polluters versus upstream or downstream of them; and (ii) the elasticities of all domestic and foreign supply and demand.

To see this, consider the linear market M1, as defined in (2), where we assume interior solutions for all producers and consumers and, for simplicity, $\beta = \tilde{\beta} = 1$:[4]

$$(2) \quad P_d = a - bD_d = \tilde{a} - \tilde{b}\tilde{D}_d - \tau_d^D$$
$$= c + kS_d + P_u$$
$$= \tilde{c} + \tilde{k}\tilde{S}_d + P_u + \tau_d^S,$$
$$P_u = f_5(Q_u^D) = \varsigma + \kappa S_u$$
$$= \tilde{\varsigma} + \tilde{\kappa}\tilde{S}_u + \tau_u^S.$$

In the online Appendix (available at http://www.aeaweb.org/articles.php?doi=10.1257/ EQ 1 aer.101.3.TK), we solve for the following equilibrium prices and quantities:

$$(3) \quad Q^* = \theta_4 - (\hat{k}\tau_d^S + \hat{b}\tau_d^D + \hat{\kappa}\tau_u^S)/\phi_1,$$
$$P_u^* = \theta_5 - \phi_2\tau_d^D - \phi_3\tau_d^S + \phi_4\tau_u^S,$$
$$P_d^* = \theta_6 - \phi_6\tau_d^D + \phi_7\tau_d^S + \phi_8 P_u^*,$$

where $Q^* = Q_d^* = Q_u^*$ and all θ_i and ϕ_i are positive and functions of the parameters in (2).[5]

From this equilibrium, we can examine the comparative statics of a carbon policy. A marginal increase in τ_u^S will increase P_u^*, while the other carbon policies will reduce it. The effects on P_d^* are more complex, as the price depends on P_u^*. Here, a marginal increase in τ_u^S will increase P_d^* because of its effect on the upstream market. A marginal increase in τ_d^D will reduce P_d^* because of a direct effect, $-\phi_6$, as well as the effect on P_u^*. Finally, the effect of τ_d^S on P_d^* depends on the parameters: the direct effect, ϕ_7, is positive, but this may be offset by the effect through the upstream market: $-\phi_3\phi_8$.

Three potential sources of foreign emissions exist in this model. First, production upstream may result in emissions, $E_u^S = r_u^S S_u$. In equilibrium,

$$(4) \quad E_u^S = r_u^S(P_u^* - \varsigma)/\kappa,$$

which are increasing in P_u^*. An example of this would be the emissions associated with producing crude oil from tar sands. Second, production downstream may result in emissions, $E_d^S = r_d^S S_d$:

$$(5) \quad E_d^S = r_d^S(P_d^* - c - P_u^*)/k,$$

which depend on both P_d^* and P_u^*. The emissions associated with refining crude oil into gasoline is an example of this. Third, emissions may result from downstream consumption of the good, $E_d^D = r_d^D D_d$:

$$(6) \quad E_d^D = r_d^D(a - P_d^*)/b,$$

which are decreasing in P_d^*. For example, consumers using gasoline to drive a car.

With this model we can demonstrate several points. First, the application of a carbon price on the point of the vertical chain responsible for carbon emissions will always lead to leakage. This is because the carbon price is applied to domestic activities alone and necessarily stimulates substitution to foreign markets. In the case of the effect of carbon prices on production, it is rather clear: all consumers substitute their purchases to (now) lower-cost foreign sources. In the case of carbon prices on downstream consumption, the effect is indirect. The consumption carbon price reduces world prices for the regulated product and its upstream inputs, thereby stimulating increased demand for those products in areas without the carbon price.

PROPOSITION 1: *For market M1, policies that directly target the source of pollution increase foreign emissions (result in leakage).*[6]

[4] While a linear model may seem restrictive, consider this a first-order Taylor approximation around an equilibrium of a more complex system. As such, only small changes in carbon prices are relevant. We assume all parameters are positive.

[5] We define $\hat{x} = x/(x + \tilde{x})$, $\phi_1 = \hat{k}\tilde{k} + \hat{b}\tilde{b} + \hat{\kappa}\tilde{\kappa}$, $\phi_2 = \hat{\kappa}\tilde{\kappa}\hat{b}/\phi_1$, $\phi_3 = \hat{\kappa}\tilde{\kappa}\hat{k}/\phi_1$, $\phi_4 = (\hat{k}\tilde{k}\hat{\kappa} + \hat{b}\tilde{b}\hat{\kappa})/\phi_1$, $\phi_5 = \tilde{b}k\tilde{k} + bk\tilde{k} + b\tilde{b}\tilde{k} + b\tilde{b}k$, $\phi_6 = bk\tilde{k}/\phi_5$, $\phi_7 = b\tilde{b}k/\phi_5$, $\phi_8 = (b\tilde{b}\tilde{k} + b\tilde{b}k)/\phi_5$, $\theta_1 = (a\tilde{b} + \tilde{a}b)/(b + \tilde{b})$, $\theta_2 = (c\tilde{k} + \tilde{c}k)/(k + \tilde{k})$, $\theta_3 = (\varsigma\tilde{\kappa} + \tilde{\varsigma}\kappa)/(\kappa + \tilde{\kappa})$, $\theta_4 = (\theta_1 - \theta_2 - \theta_3)/\phi_1$, $\theta_5 = \hat{\kappa}\tilde{\kappa}\theta_4 + \theta_3$, and $\theta_6 = (a\tilde{b}k\tilde{k} + b\tilde{b}c\tilde{k} + \tilde{a}bk\tilde{k} + b\tilde{b}\tilde{c}k)/\phi_5$. Positive ϕ_i follows directly from the parameters. Positive prices and quantities imply positive θ_i.

[6] Here is the proof of this proposition. Note that $\phi_8 = x/(x + v) < 1$, where x and v are positive. Thus, $\partial E_u^S/\partial\tau_u^S = r_u^S\phi_4/\kappa$, $\partial E_d^S/\partial\tau_d^S = r_d^S[\phi_7 + (1 - \phi_8)\phi_3]/k$, and $\partial E_d^D/\partial\tau_d^D = r_u^S(\phi_6 + \phi_2\phi_8)/b$ are positive.

Second, within our model, what we call *indirect* prices on either the upstream inputs or downstream consumption of the product will *not* lead to leakage. In fact, foreign emissions may decrease.[7] The advantage of an upstream carbon price in regulating downstream emissions is that the carbon price affects input prices of both domestic and foreign downstream products. For example, a Canadian tax on oil production would reduce emissions from the US transportation sector. Similarly, by reducing global demand for a product, a domestic consumption carbon price reduces upstream supply from both foreign and domestic producers.[8] Intuitively, and as demonstrated by the model, the effectiveness of any of these policies in terms of reducing overall emissions will depend upon the critical parameters such as the elasticity of domestic and foreign supply and demand, as well as relative emissions rates.

PROPOSITION 2: *For market M1, upstream policies decrease downstream foreign emissions, and downstream policies decrease upstream foreign emissions.*[9]

PROPOSITION 3: *For market M1, the magnitude of the effectiveness of all policies, and sign of some, depends on the parameters of domestic and foreign supply and demand.*[10]

To compare policies of equal domestic effectiveness, we calculate the effect of policy i on domestic emissions at source j, $\partial \tilde{E}_j / \partial \tau_i$. The ratio of the marginal leakage over the marginal reduction in domestic emissions is the same for policies that do not directly target foreign emissions, $i \neq j$.[11] Perhaps more important is the net effect on global emissions, $\partial E_j / \partial \tau_i + \partial \tilde{E}_j / \partial \tau_i$, where the relative ranking of the policies depends on the parameters of the model.[12] Namely, the implications of vertical targeting on global emissions depend on the elasticities of all market participants.

III. Discussion and Extensions

Our model shows when upstream regulation may be preferable to downstream, and vice versa. There is another advantage of placing the point of regulation on the upstream input. Namely, it is not as vulnerable to the reshuffling of the relationship between specific suppliers and consumers as is downstream regulation on consumers. This point is not directly addressed in this model, as the taxes we examine are effectively on products, rather than emissions. This is because our model does allow for endogenous domestic and foreign emissions rates. A tax on the consumption of "dirty" inputs would create a domestic separation in prices between foreign and domestic inputs, while internationally the two products would trade at the same price. In this circumstance, the "dirty" inputs would flow to the markets where the tax penalty would not apply to them.

However, an upstream tax on the production of dirty inputs would shift inward the supply of those inputs to *all* markets. If the emissions are downstream, this will unambiguously reduce emissions, although if the emissions reside in the production of the input itself, there will be leakage from the "direct" effect of the regulation by shifting production of the input from the domestic market. Thus, for example, a tax on US cement, while decreasing world consumption of related downstream products, could increase emissions

[7] Don Fullerton and Dan Karney (2011) also find negative leakage in a model with two sectors competing over capital. When one market is regulated and increases demand for capital, this has spillovers to the other market and reduces emissions everywhere.

[8] A special case arises when the upstream product is an exhaustible resource. In that situation, reducing domestic demand results in shifting consumption over time or space (Fischer and Steven Salant 2010).

[9] Using Proposition (1)'s proof, $\partial E_u^S / \partial \tau_d^S = -r_u^S \phi_3 / \kappa$, $\partial E_u^S / \partial \tau_d^D = -r_u^S \phi_2 / \kappa$, $\partial E_d^S / \partial \tau_u^S = -r_d^S (1 - \phi_8) \phi_4 / k$, and $\partial E_d^D / \partial \tau_u^S = -r_u^S \phi_4 \phi_8 / b$ are negative.

[10] From the proofs of Propositions (1) and (2), the magnitude of the partial derivatives depend on the parameters. The effect of a downstream demand policy on emissions from downstream foreign supply $(\partial E_d^S / \partial \tau_d^D = -r_d^S [\phi_6 - (1 - \phi_8) \phi_2] / k)$, and the effect of a downstream supply policy on emissions from downstream foreign demand $(\partial E_d^D / \partial \tau_d^S = -r_u^S (\phi_7 - \phi_3 \phi_8) / b)$, depend on the parameters.

[11] For example, downstream suppliers emit $\tilde{E}_d^S = \tilde{r}_d^S (P_d - \tilde{c} - P_u - \tau_d^S) / \tilde{k}$. Thus, the ratio of the marginal leakage over the marginal reduction in domestic emissions is $r_d^S \tilde{k} / \tilde{r}_d^S k$ for policies that do not directly target foreign emissions.

[12] For example, if all b, k, and κ parameters equal one, then global emissions of source j decrease by $(2\tilde{r}_j - r_j)/3$ for direct policies and by $(\tilde{r}_j + r_j)/6$ for indirect ones. Thus, if domestic emitters have higher rates than their foreign counterparts, direct policies will be more effective. However, if foreign emitters are dirtier $(r_j > 2\tilde{r}_j)$, then global emissions rise with direct policies.

by stimulating production from less efficient Chinese facilities.

Note the potential role of border adjustments here. If an import tariff were applied to an upstream product *in addition* to a production charge, the policy resembles a tax on consumption of the upstream product, which is in turn equivalent to a tax on downstream production in our model. For a net importing nation, the border adjustment, therefore, can turn a direct policy that creates leakage into an indirect one that results in negative leakage. However, for regions that are net exporters, border adjustments as they are typically conceived would not eliminate positive leakage. In this case, the increase in foreign emissions stems from *reduced* exports from the regulated sector, rather than increased imports.

There are several useful extensions to be pursued of even this basic model. The current model has strong assumptions that may be relaxed in future work: the production function (fixed β), emissions rate (fixed r), linear functions, competitive markets, and vertical structure. A natural extension is the imposition of a carbon, rather than unit, tax on the various sectors. In the absence of technology to mitigate emissions, such a tax would not stimulate cleaner production. However, when a reduction of emissions rates is feasible, as in the case of switching to lower-carbon fuels, taxing emissions rather than production or consumption would have a different effect. Furthermore, within the context of this model, such a differentiated tax can capture further effects of indirect regulations such as reshuffling.

IV. Conclusion

This paper develops a simple model to evaluate the effects of upstream versus downstream regulation on leakage. Namely, if countries do not harmonize carbon prices, then concern has been voiced that domestic production would be replaced by firms in unregulated or less regulated nations. The implications of this paper are that direct regulation at the point of emissions results in leakage. However, indirect policies, such as a carbon price on upstream supply to address emissions from downstream consumption, may actually reduce emissions in other countries. We find that the elasticities of demand and supply affect the marginal effects of upstream and downstream policies on emissions in unregulated countries.

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