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Abstract

We build a simple analytical general equilibrium model and linearize it, to find a closed-from expression for the effect of a small change in carbon tax on leakage – the increase in emissions elsewhere. The model has two goods produced in two sectors or regions. Many identical consumers buy both goods using income from a fixed stock of capital that is mobile between sectors. An increase in one sector's carbon tax raises the price of its output, so consumption shifts to the other good, causing positive carbon leakage. However, the taxed sector substitutes away from carbon into capital. It thus absorbs capital, which shrinks the other sector, causing negative leakage. This latter effect could swamp the former, reducing carbon emissions in both sectors.

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A common concern with a unilateral pollution restriction is that one country's abatement will be offset by "leakage", defined as the increase in pollution elsewhere. Within a country as well, cap-and-trade may apply only to one sector such as electricity, which raises its price and shifts consumption to goods produced in other unregulated sectors. Purely domestic leakage may offset some of the regulated sector's abatement. In an international context, even without international capital flows, the regulating country puts itself at a competitive disadvantage. International capital mobility is thought to make leakage worse, if investment flees the taxed region to help produce more polluting output in the other region. In the context of climate policy, carbon leakage is a particular concern due to the global impacts of greenhouse gases.

The literature has many estimates for carbon leakage associated with the Kyoto Protocol. For instance, Paltsev (2001) finds a leakage rate of 10%, whereas Babiker (2005) finds rates as high as 130%. In that case, a carbon tax in one country raises worldwide emissions. More typical of other recent estimates, Elliott *et al.* (2010) find a 20% carbon leakage rate from the Annex-B Kyoto countries.

Given this presumption that leakage is positive, academics have searched for particular cases with counter-intuitive results. We cannot review all such literature, but we list a few examples. First, Felder and Rutherford (1993) build a computable general equilibrium (CGE) model with five regions and ten-year intervals, finding that marginal leakage can be negative after several decades if the carbon tax leaves enough unused oil to delay the other region's introduction of carbon-intensive synthetic fuel. Second, Copeland and Taylor (2005) show how negative leakage can arise through endogenous policy: in response to a cut in one region's emissions, the other region experiences income gains that induce them to choose more environmental quality by raising their own pollution tax. Third, negative leakage can arise through endogenous technology: the carbon tax may induce R&D into new abatement technology that can be used by the unregulated sector, especially if patents are poorly protected.[1] Fourth, Karp (2010) follows Chua (2003) to find negative leakage in an "extreme example" with particular cross-price elasticities among three inputs (such as labor, capital, and emissions).[2]

[1] See Golombek and Hoel (2004), Di Maria and Smulders (2004), Gerlagh and Kuik (2007), and Di Maria and van der Werf (2008). Each makes particular points, which we cannot review here.

[2] In Karp's example, production is highly labor intensive, but the carbon tax induces much substitution into capital, so it can reduce the return to labor, promote production, and reduce import demand for the dirty good. In a closed economy, Fullerton and Heutel (2007) show that such special cases can generate other perverse results; a carbon tax can even raise emissions in the taxed sector.

In this note, we demonstrate a substantial negative effect on leakage that has not been identified in existing literature, using a very general and simple model without special cases, particular parameters, endogenous policy, or induced technology change. Indeed, the model is a very standard analytical general equilibrium model with only two competitive sectors that each use carbon and one other input, with constant returns to scale. Then a carbon tax always raises costs in that sector. We derive expressions that show exactly when the negative effect on leakage in this model could swamp the positive effect, such that global carbon emissions fall by more than in the taxed sector.

Our model can be taken to represent two countries that each produces one good, or a closed economy that produces two outputs. For instance, the carbon policy could apply to electricity generation and not other goods, or it could apply in only one region within a country.[3] Many identical consumers earn income from a fixed stock of capital, and they receive rebate of all tax revenue. Positive leakage arises when consumers substitute from the taxed country or sector's output to the other output. If the context were two countries that produce the *same* traded good (like steel from the U.S. or China), then a carbon tax in one country always increases imports and leakage.

To find a negative leakage effect, we use three reasonable, general assumptions. First, the two goods are not perfect substitutes. Consumers still cause leakage when they substitute into the untaxed good, but not perfectly via infinite elasticity of substitution. Second, we assume that the firm has some ability to substitute out of carbon and into the other input (which can be labor, capital, or a composite of both). The elasticity of substitution in production is not zero, so firms can reduce carbon per unit of output by using 'abatement resources.' Third, the clean input is mobile between the two sectors or countries. These assumptions do not represent a "special case". Rather, they are generalizations of prior models that assume capital is not mobile, or that firms cannot change carbon per unit of output, or that the two goods must be identical.

Given these conditions, the result is quite easy to explain. A carbon tax or permit price induces firms to abate carbon per unit of output by using more of a clean input such as abatement capital. The taxed sector draws resources away from the unregulated sector or region, which reduces their output and emissions. We call this an

[3] As an example of sub-national policy, the Regional Greenhouse Gas Initiative (RGGI) is a conglomerate of Northeastern states in the U.S. that agree to limit their own carbon emission. Wing and Kolodziej (2009) find carbon leakage rates of more that 50%, due to electricity imports from non-RGGI states.

"abatement resource effect" (ARE). Its size depends on parameters. If consumers can shift their purchases easily, then positive leakage may be high. Even then, however, leakage may be overstated in models that do not allow for substitution in production. If consumer flexibility is low compared to producers' ability to abate pollution by use of other resources, however, then we show that overall leakage may be negative.

Given the simplicity of this intuitive result, we wonder why previous literature has not identified this effect. First, some models assume fixed carbon per unit of output (with no substitution into a clean input). Second, some models assume that capital and labor are not mobile between countries. They might assume that factors are mobile between sectors within a country but then find effects of a tax on all carbon in that country, leaving no scope for firms to draw resources from an untaxed sector. Third, some CGE models may incorporate all three of our key assumptions but then report net numerical results, obscuring the fact that our ARE offsets some of the positive leakage. In any case, we do not find any paper that derives analytical expressions for leakage in a model where firms can substitute into a clean input that is mobile across regions.

Our intent is to demonstrate this effect using the simplest possible model, not to measure actual leakage. We therefore abstract from many important issues such as materials production and intermediate inputs [e.g. Felder and Rutherford (1993)], endogenous number of firms [Gurtzgen and Rauscher (2000)], oligopolistic competition [Babiker (2005)], and strategic interaction [Fowlie (2009)].[4] Such features could affect leakage, but none would remove the ARE in our expressions. In any model with the three assumptions above, results would still include this negative leakage term.

The next section presents our basic model. In section 2, we differentiate all equations to linearize the model and solve for effects of a small increase in one sector's pollution price. We identify the abatement resource effect in a closed-form expression for the change in carbon leakage. Section 3 provides a brief numerical example, while Section 4 provides further discussion. We investigate the ARE further, to see whether output in the other sector falls because revenue from the increased tax is not enough to compensate consumers for the higher price of one good. In some cases, the additional revenue is negative, which itself reduces consumer purchases.

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[4] Our model is also related to Holland (2009), who shows that welfare gains might be higher with an intensity standard than with a tax on emissions, because it causes less increase in the output price and therefore less leakage. Without an overall resource constraint, however, he cannot find negative leakage.

1. The Basic Model

Two competitive sectors ($i = X,Y$) each use clean input K_i and carbon emissions C_i with decreasing marginal products in a constant returns to scale production function, $X = X(K_X, C_X)$ and $Y = Y(K_Y, C_Y)$. The clean input is mobile and thus earns the same return, p_K, in either sector. It can be considered a composite of labor and capital, in fixed total supply $\left(\overline{K} = K_X + K_Y\right)$. Each sector faces its own carbon tax τ_i (or permit price for carbon).[5] In response to an increased tax on emissions, a firm can reduce its carbon per unit of output by additional use of abatement technology, that is, by substitution from C_i into K_i. In the electricity generating sector, for example, firms can reduce emissions per kilowatt-hour by investing in natural gas plants, wind turbines, or solar power. All revenue is returned via lump-sum rebate, $R \equiv \tau_X C_X + \tau_Y C_Y$.

This model omits a type of positive leakage, namely, world trade of fossil fuel in fixed supply. If a taxing country reduces its demand for oil, the fall in the world price of oil can increase consumption elsewhere.[6] Instead, consider τ_Y on coal-fired power plants, where coal is not scarce (its world price depends primarily on extraction cost).

Emissions from either sector add to total carbon, $C \equiv C_X + C_Y$, which negatively affects utility in a separable manner. Many identical households earn income from capital and the rebate of revenue, taking as given the total carbon and all market prices (p_X, p_Y, and p_K). They maximize homothetic utility by choice of X and Y:

$$\max_{\{X,Y\}} U(X,Y;C) \quad s.t. \quad p_K\overline{K} + R \geq p_X X + p_Y Y \,.$$

We have no need to specify which sector initially has the higher carbon tax rate, and so we simply investigate effects of a small increase in τ_Y with no change in τ_X. We compare the new long run equilibrium to the initial one, ignoring adjustments during the transition. The increase in τ_Y reduces equilibrium emissions in sector Y, and so leakage is defined as the effect on emissions in sector X.

[5] Variable supply of labor or capital (factor K) would not remove negative leakage: whatever the new supply of K, the use of K for abatement in sector Y must come at the expense of output X. However, input C is not in fixed total supply in any "market" for carbon (or fossil fuels). We just assume each firm can use any amount of C, given the tax rate. With no uncertainty, however, the resulting choice for carbon quantity at tax rate τ can equally represent a policy with that number of permits at price τ.

[6] This other type of leakage might be important with border tax adjustments (BTA), which essentially convert a tax on carbon in production to a tax on carbon in consumption. We model a carbon tax with no border tax adjustments, that is, without such effect on the world oil price. In any case, adding oil as an input would change the model, and leakage, but it would not remove the ARE.

This simple model can be interpreted at least two ways. First, it can represent an international context where Y is produced in one country or set of countries that raises its carbon tax, while X is produced in the "rest of world". In this case, we suppose that all consumers have the same utility function.[7] Capital is owned by these identical worldwide consumers, and it can be used to produce either region's output. A more complete trade model might have both regions produce both outputs, with the same type of negative leakage that we identify (so long as firms can substitute into mobile capital).

Alternatively, the model can represent a closed economy in which only sector Y faces a raised price of carbon. For a concrete example that "best" fits our model, the European Union's Emission Trading System (EU-ETS) applies to electricity generation and major industries, including only 40% of total E.U. greenhouse gas (GHG) emissions.[8] Any agreement between the E.U. and the U.S. or other nations may apply GHG or carbon pricing to a similar subset of outputs (with the usual problems of aggregation). This example is particularly appropriate, because electricity has inelastic demand, which means low elasticity of substitution in utility – one condition that increases the size of negative leakage in our model.

2. Solving for Equilibrium Effects

Given this set-up, we now log-linearize the model to solve for n linear equations in n unknowns. Totally differentiate the resource constraint $\overline{K} = K_X + K_Y$, and use the "hat" notation to denote a proportional change in any variable (e.g. $\hat{K}_X \equiv dK_X / K_X$):

$$0 = \alpha_X \hat{K}_X + \alpha_Y \hat{K}_Y \tag{1}$$

where $\alpha_i \equiv K_i / \overline{K}$ is the share of capital in production of i ($i = X,Y$), and $\alpha_X + \alpha_Y = 1$. Then totally differentiate production to show how changes to inputs affect final output:

$$\hat{X} = \theta_{XK} \hat{K}_X + \theta_{XC} \hat{C}_X \tag{2}$$

$$\hat{Y} = \theta_{YK} \hat{K}_Y + \theta_{YC} \hat{C}_Y \tag{3}$$

where θ_{ij} is the factor share of income for input j in the production of good i [e.g. θ_{XK}

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[7] Our model with a single type of worldwide consumer is not adequate to analyze effects on welfare in each country, but our goal here is only to look at effects on carbon emissions in each country.

[8] See http://ec.europa.eu/clima/policies/ets/index_en.htm.

$\equiv (p_K K_X)/(p_X X)]$. Then $\theta_{XK} + \theta_{XC} = 1$ and $\theta_{YK} + \theta_{YC} = 1$.

Perfect competition and constant returns to scale imply zero profits, so $p_X X = p_K K_X + \tau_X C_X$ and $p_Y Y = p_K K_Y + \tau_Y C_Y$. Totally differentiate these equations and use the firm's profit maximizing first-order conditions:

$$\hat{p}_X + \hat{X} = \theta_{XK}\left(\hat{p}_K + \hat{K}_X\right) + \theta_{XC}\left(\hat{\tau}_X + \hat{C}_X\right) \tag{4}$$

$$\hat{p}_Y + \hat{Y} = \theta_{YK}\left(\hat{p}_K + \hat{K}_Y\right) + \theta_{YC}\left(\hat{\tau}_Y + \hat{C}_Y\right) \tag{5}$$

Each production function has only two inputs, so factor intensity responds to a change in relative input prices according to each elasticity of substitution, σ_X and σ_Y. We define these elasticities to be positive. Differentiating their definitions yields:

$$\hat{C}_X - \hat{K}_X = \sigma_X\left(\hat{p}_K - \hat{\tau}_X\right) \tag{6}$$

$$\hat{C}_Y - \hat{K}_Y = \sigma_Y\left(\hat{p}_K - \hat{\tau}_Y\right). \tag{7}$$

Finally, under the assumption that pollution is separable in utility, we use the single parameter σ_U to define the elasticity of substitution in utility between X and Y. Differentiating the definition of σ_U yields:

$$\hat{X} - \hat{Y} = \sigma_U\left(\hat{p}_Y - \hat{p}_X\right). \tag{8}$$

Suppose β is the share of income spent on Y, and η_{YY} is the usual own-price elasticity of demand (with no change in any other prices). Then one can easily show $\eta_{YY} = -[\beta + \sigma_U(1-\beta)]$. In other words, a small σ_U can represent the trade-off between Y, a good like electricity with inelastic demand, and all other goods X.

Equations (1) – (8) are the log-linear system for general equilibrium effects of a small change in policy. We define capital as numeraire ($\hat{p}_K = 0$), which leaves the eight numbered equations above with eight unknowns (changes in X, Y, their two prices, and the four input quantities). We assume $\hat{\tau}_X = 0$, where $\hat{\tau}_Y$ is a small positive exogenous change in tax. Sector X experiences no change in relative input prices $\left(\hat{\tau}_X = \hat{p}_K = 0\right)$, so equation (6) simplifies to $\hat{C}_X = \hat{K}_X$. Note, we do not assume Liontief production in X. Those firms have a positive σ_X, but they *choose* not to alter input ratios because they face no relative input price changes. In addition, unchanged input prices means no change in the breakeven output price, so $\hat{p}_X = 0$ [from equations (2) and (4)].

Next, observe from (3) and (5) that $\hat{p}_Y = \theta_{YC}\hat{\tau}_Y > 0$. This additional carbon tax always raises the price of Y relative to the price of X. Further algebra reveals:

$$\hat{Y} = -[\alpha_X \sigma_U + \alpha_Y \sigma_Y]\theta_{YC}\hat{\tau}_Y \tag{9}$$

Since all parameters in this equation are positive, the negative sign out front means that the increase in τ_Y unambiguously reduces output – to an extent that depends on substitution elasticities and the carbon share of production. Algebra also yields:

$$\hat{C}_Y = \left[\underbrace{-(\alpha_X \sigma_U + \alpha_Y \sigma_Y)\theta_{YC}}_{\substack{\text{Output}\\ \text{Effect}}} - \underbrace{\theta_{YK}\sigma_Y}_{\substack{\text{Substitution}\\ \text{Effect}}} \right]\hat{\tau}_Y \tag{10}$$

The second term inside the large brackets is the "substitution effect", since the tax changes relative input prices and induces substitution through the elasticity σ_Y. Firms reduce carbon per unit of output. Then the first term is just $\hat{Y}$, from (9). It represents an "output effect", since the tax raises output price and reduces demand, so firms further reduce both inputs. The tax on carbon reduces carbon emissions through both of these channels, and so (10) shows that $\hat{C}_Y$ is unambiguously negative.

Two effects operate in different directions in the other sector, however:

$$\hat{C}_X = \alpha_Y(\sigma_U - \sigma_Y)\theta_{YC}\hat{\tau}_Y = \left[\underbrace{\sigma_U \alpha_Y \theta_{YC}}_{\text{TTE}} - \underbrace{\sigma_Y \alpha_Y \theta_{YC}}_{\text{ARE}} \right]\hat{\tau}_Y \tag{11}$$

The first effect in (11) is a terms-of-trade effect (TTE), because the higher price of Y induces consumer substitution into X (to an extent that depends on σ_U). Alone, it would raise production of X and therefore raise C_X (positive leakage). The other term in (11) is what we call the abatement resource effect (ARE). It depends on σ_Y, because the firms in Y substitute from carbon into capital for abatement, and thus bid capital away from X. Since $\hat{\tau}_X = \hat{p}_K = 0$, those firms choose not to substitute and instead reduce both K_X and C_X. This term yields negative leakage.

Clearly, from (11), the relative size of these offsetting effects depends on the relative size of σ_U and σ_Y. If consumers can substitute easily between goods, then the terms-of-trade effect dominates, and leakage is positive. This effect would be large for the case with international trade in close substitutes. Using the Armington (1969) assumption, for example, then σ_U would be large, and leakage is positive. Even in that case, however, researchers might overstate leakage if they do not allow for any negative effect on leakage through home substitution into abatement capital (the ARE effect).

In other cases such as the pricing of carbon permits in the electricity sector, demand is inelastic, and so σ_U is small. If technology allows for abatement per unit of output, then σ_Y may exceed σ_U, and overall leakage is negative. In this case, models that ignore the ARE would find the wrong sign for overall leakage. The net effect of unilateral pollution regulation could be overall pollution reduction beyond what is achieved within the regulating sector, region, or country.

3. Numerical Magnitudes

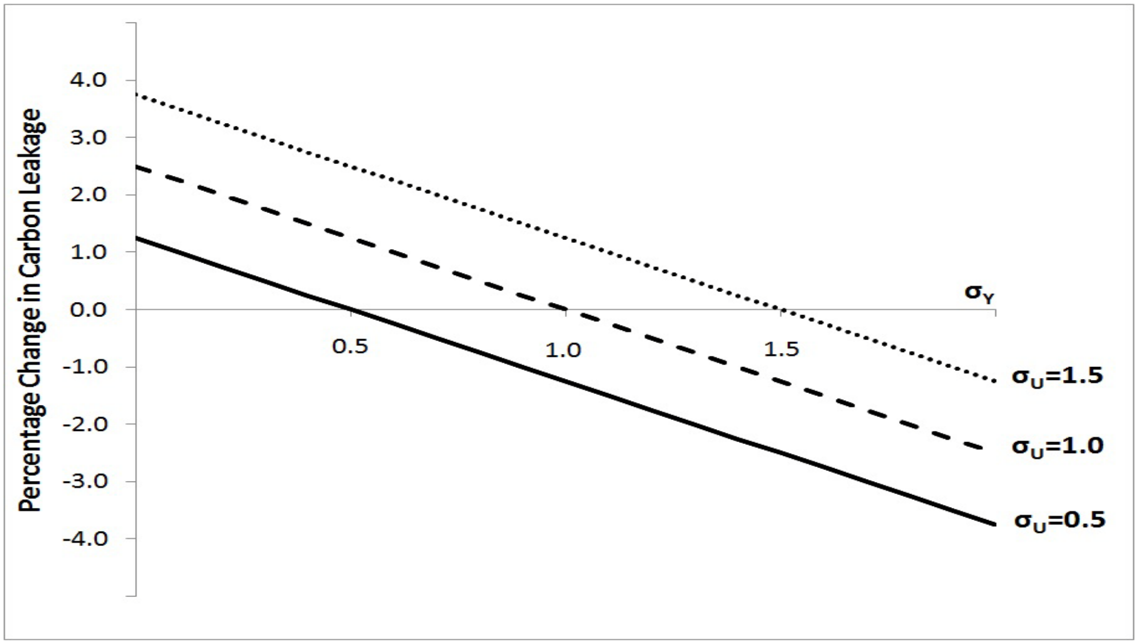
To see the size of these effects, we assign values to parameters and calculate the leakage response to a 10% increase in tax $(\hat{\tau}_Y = 0.1)$. To calculate $\hat{C}_X$ in (11), however, we need four parameters. First, we set the initial carbon intensity $(\theta_{YC} = 0.5)$ and allocate half of capital to each sector $(\alpha_X = \alpha_Y = 0.5)$ Then in figure 1, we show carbon leakage on the vertical axis as a function of the elasticity of substitution in production (σ_Y). The top dotted line in the figure is for σ_U =1.5, where leakage declines from +4.0% to –1.5% as σ_Y varies from zero to 2.0 on the horizontal axis. Thus negative leakage is possible, even with high σ_U, but it is more likely with lower σ_U. The middle dashed line is for σ_U =1.0, and the bottom solid line is for σ_U =0.5, where leakage declines from +1.0% to –4.0% as σ_Y varies from zero to two.

Perhaps the overall point is clear from equation (11), but figure 1 conveys size and makes it visual: negative leakage is possible, and it is made more possible by high values of σ_Y (where substitution into abatement technology is easier) or low values of σ_U (where consumers buy nearly as much of the taxed sector's output).

4. Discussion

This analysis raises at least four questions, which we now address. First, many have wondered how factor prices can remain unchanged in sector X. Does the interpretation depend on the choice of numeraire? We chose $\hat{p}_K = 0$ as numeraire, and we found that $\hat{p}_X = 0$, so the choice of X as numeraire would yield exactly the same results. Yet we also assume $\hat{\tau}_X = 0$, which means that policymakers hold constant the tax on carbon in sector X relative to either their output price or input price. Only relative prices matter, so it seems reasonable that the other country would hold constant its tax relative to its own prices. Yet, suppose that policymakers were to hold τ_X constant relative to p_Y (or to some overall weighted average price level). Since p_Y rises, that would *raise* τ_X relative to our numeraire (p_K or p_X), which would *reduce* leakage. In this respect, our assumption yields a conservative expression for negative leakage.

Figure 1 – Carbon Leakage Depends on σ_Y and σ_U [θ_{YC}=0.5, $\alpha_X = \alpha_Y$ =0.5, $\hat{\tau}_Y$ =0.1]



Second, we find that leakage $\hat{C}_X$ is negative when output declines ($\hat{X}$ <0), but how is that consistent with a decline in the relative price of X? Recall that $\hat{p}_Y$ >0, while $\hat{p}_X$ =0. Does demand for X have the wrong slope? No, we can calculate the usual own-price elasticity of demand for X with no change in other prices, $\eta_{XX} = -[(1-\beta) + \sigma_U\beta]$, which is clearly negative. A fall in p_X alone would raise X, partly because it increases real income. In contrast, the increase in p_Y reduces real income and therefore tends to decrease world demand for both goods. In fact, the cross-price elasticity of demand for X with respect to a change in p_Y is $\eta_{XY} = \beta(\sigma_U-1)$, which can have either sign.

Third, however, consumers receive back all of the tax revenue, so how can this *compensated* increase in p_Y/p_X reduce X? Recall that consumers earn $I = p_K\overline{K} + R$, where $R = \tau_Y C_Y + \tau_X C_X$. The answer is that the rebate of revenue is never enough to reach the same indifference curve, especially since the increase in the input tax worsens production inefficiency, shifting inward the production possibility frontier. An increase in the distorting tax τ_Y always reduces the utility from consumption (even if it provides benefits from a better environment). In fact, increasing deadweight loss from an input tax is the reason for a Laffer Curve, where revenue is a hump-shaped function of the tax rate. Initial increases in τ_Y may raise positive revenue, but successive increases yield zero and then negative revenue.

Fourth, we wonder if our negative leakage result is related to this insight about the Laffer curve. Is the sign of $\hat{C}_X$ related to the sign of $\hat{R}$? As it turns out, the set of parameters for which leakage is negative is not a subset of the parameters for which the effect on revenue is negative, nor the other way around.

Since the capital stock and its price are fixed, the only change to income is the change in the rebate of revenue. We totally differentiate that expression for *R* and find:

$$\hat{R} = \{(\alpha_Y - \delta_Y)\theta_{YC}(\sigma_U - \sigma_Y) - \delta_Y \sigma_Y + \delta_Y\}\hat{\tau}_Y \qquad (12)$$

where $\delta_X \equiv \tau_X C_X / R$, $\delta_Y \equiv \tau_Y C_Y / R$, and $\delta_X + \delta_Y = 1$; that is, δ_X is the share of total tax revenue from sector *X*.

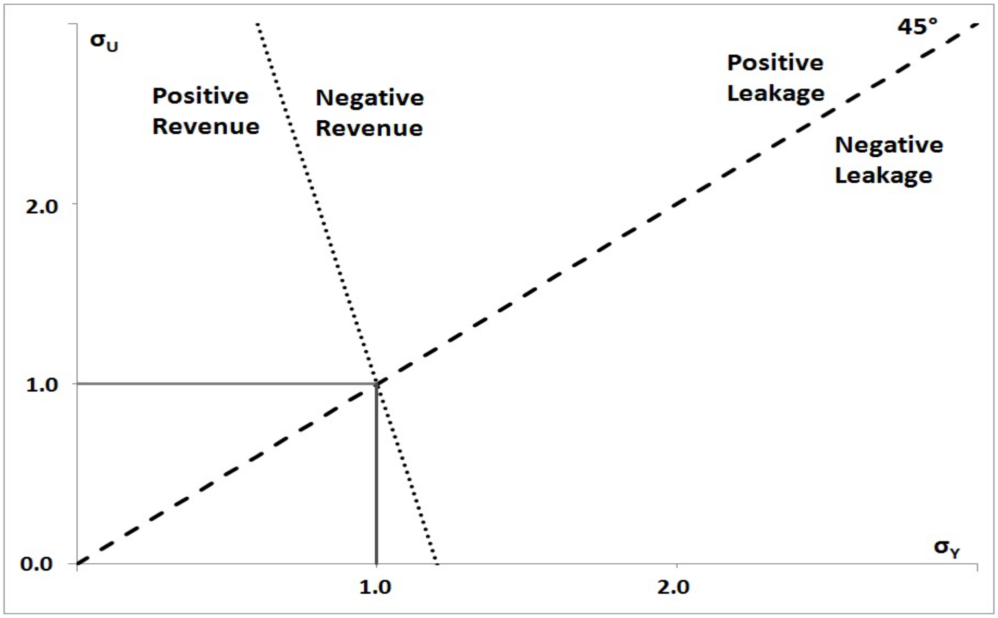
To see how the change in revenue and leakage each depend on substitution parameters, figure 2 plots σ_Y on the horizontal axis and σ_U on the vertical axis. First note that $\hat{C}_X$ in equation (11) has a term ($\sigma_U - \sigma_Y$) times $\hat{\tau}_Y$, so leakage is zero whenever $\sigma_U = \sigma_Y$ (on the 45 degree dashed line in figure 2). Leakage is positive to the upper-left of that line (with higher σ_U) and negative to the lower-right (with higher σ_Y).

To find areas for positive or negative changes in revenue in figure 2, we set $\hat{R} = 0$ in equation (12) and solve:

$$\sigma_U = \left(1 - \frac{\delta_Y}{\theta_{YC}(\delta_Y - \alpha_Y)}\right)\sigma_Y + \left(\frac{\delta_Y}{\theta_{YC}(\delta_Y - \alpha_Y)}\right) \qquad (13)$$

This line has a slope that depends on the sign and magnitude of ($\delta_Y - \alpha_Y$). If the share of tax revenue from sector Y exceeds its share of capital ($\delta_Y > \alpha_Y$), then this slope can be negative. Figure 2 depicts the case where $\delta_Y = 0.75$, and $\alpha_Y = 0.5$, using a dotted iso-revenue line. To the lower-left, where both σ elasticities are small, the increase in τ_Y raises revenue; to the upper right of this line, the larger responsiveness means that an increase in τ_Y reduces the tax base by enough that revenue falls. If $\delta_Y = \alpha_Y$, then the line is vertical, and if $\alpha_Y > \delta_Y$ the slope is positive. The iso-leakage and iso-revenue lines always intersect where σ_U and σ_Y both equal one. In any case, the figure clearly shows four different areas: the signs of ($\hat{C}_X$, $\hat{R}$) can be (+,+), (+,-), (-,+), or (-,-).

Figure 2 – Tax in Sector Y Yields Most Revenue (δ_Y=0.75, θ_{YC} =0.5, $\alpha_X = \alpha_Y$ =0.5)



So far, leakage seems unrelated to revenue. But suppose the initial τ_Y is zero, with no revenue from sector Y ($\delta_Y = 0$). Then equation (13) shows that the iso-revenue line has an intercept of zero and a slope of one. In this case, it is coincident with the iso-leakage line. In other words, an initial increase in τ_Y from zero necessarily has both negative leakage and negative net revenue whenever $\sigma_Y > \sigma_U$. The initial increase in τ_Y induces sector Y to substitute into abatement, which draws capital away from sector X. The output of X shrinks, along with both of its inputs. Less C_X means negative leakage, and it also means less revenue from $\tau_X C_X$.

The point of our paper is not that leakage must be negative. Various extensions might reduce the size of our negative leakage effect. Rather, we show that in some cases leakage might be negative. More importantly, policymakers and economists who ignore the abatement resource effect might be overstating the size of carbon leakage.

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