Competitiveness and Carbon Taxes

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Abstract

Blah blah blah

1 Leakage

We focus on the case of $\eta = 1$, in which energy is consumed only indirectly through consumption of manufactures. In that case emissions show up in four terms: M_e^{HH}, M_e^{FH}, M_e^{HF}, and M_e^{FF} (the first subscript is the point of consumption and the second the point of production). The total is:

$$M_e = M_e^{HH} + M_e^{FH} + M_e^{HF} + M_e^{FF}$$

In a baseline of no carbon taxes, the fraction of emissions due to *production* in $\mathcal{F}$ is:

$$\begin{aligned}\frac{M_e^{HF} + M_e^{FF}}{M_e} &= \frac{p_e M_e^{HF} + p_e M_e^{FF}}{p_e M_e} = \frac{(1-\gamma)\left(1-\bar{j}\right)\left(\pi_c Y + \pi_c^* Y^*\right)}{(1-\gamma)\left(\pi_c Y + \pi_c^* Y^*\right)} \\ &= 1 - \bar{j},\end{aligned}$$

where $\bar{j}$ is $\mathcal{H}$'s market share in tradable manufactures. The fraction of emissions due to *consumption* in $\mathcal{F}$ is:

$$\frac{M_e^{FH} + M_e^{FF}}{M_e} = \frac{(1-\gamma)\,\pi_c^* Y^*}{(1-\gamma)\left(\pi_c Y + \pi_c^* Y^*\right)} = 1 - \omega_c,$$

where

$$\omega_c = \frac{\pi_c Y}{\pi_c Y + \pi_c^* Y^*}$$

is $\mathcal{H}$'s share of world spending on the c-good.

We consider carbon policy in $\mathcal{H}$ consisting of a combination of a production tax t'_p and a border tax adjustment $t'_b \in [0, t'_p]$. With no border adjustments ($t'_b = 0$) it is a pure production tax (at rate t'_p) while with full border adjustments ($t'_b = t'_p$) it is a pure consumption tax (at rate t'_b). It is often helpful to parameterize carbon taxes in terms of the border adjustment t'_b and the effective production tax $\tilde{t}'_p$, satisfying:

$$1 + \tilde{t}'_p = \frac{1 + t'_p}{1 + t'_b}.$$

In this space, there are no constraints on the tax rates, other than $t'_b \geq 1$ and $\tilde{t}'_p \geq 1$.

The proportional reduction in global emissions $G < 1$ under such policies is acheived through reduced demand for energy, which drives down the price of energy faced by the extraction sector, leading that sector to supply less energy on the world market. This reduction in the price of energy $\hat{p}_e$, known as the *fuel price effect*, is connected to the reduction in global emissions via the energy supply curve:

$$\hat{p}_e = G^{(1-\beta)/\beta}. \tag{1}$$

The effect of such policies on changes in the four types of energy use are given by:

$$\hat{M}_e^{HH} = \frac{\bar{j}'}{\bar{j}} \frac{\hat{\pi}_c \hat{Y}}{\left(1 + t'_p\right) \hat{p}_e},$$

$$\hat{M}_e^{FH} = \frac{\bar{j}'}{\bar{j}} \frac{\hat{\pi}_c^* \hat{Y}^*}{\left(1 + \tilde{t}'_p\right) \hat{p}_e},$$

$$\hat{M}_e^{HF} = \frac{1 - \bar{j}'}{1 - \bar{j}} \frac{\hat{\pi}_c \hat{Y}}{(1 + t'_b)\, \hat{p}_e}$$

and

$$\hat{M}_e^{FF} = \frac{1 - \bar{j}'}{1 - \bar{j}} \frac{\hat{\pi}_c^* \hat{Y}^*}{\hat{p}_e}.$$

The goal of the carbon tax policy in $\mathcal{H}$ is to reduce global emissions, the source of climate change. We can express G in terms of the four terms above as:

$$\begin{aligned}
G &= \frac{M_e^{HH}\hat{M}_e^{HH} + M_e^{FH}\hat{M}_e^{FH} + M_e^{HF}\hat{M}_e^{HF} + M_e^{FF}\hat{M}_e^{FF}}{M_e^{HH} + M_e^{FH} + M_e^{HF} + M_e^{FF}} \\
&= \omega_c \bar{j}\hat{M}_e^{HH} + (1-\omega_c)\,\bar{j}\hat{M}_e^{FH} + \omega_c\,(1-\bar{j})\,\hat{M}_e^{HF} + (1-\omega_c)\,(1-\bar{j})\,\hat{M}_e^{FF} \\
&= \bar{j}'\left(\omega_c \frac{\hat{\pi}_c \hat{Y}}{(1+t_p')\,\hat{p}_e} + (1-\omega_c)\,\frac{\hat{\pi}_c^* \hat{Y}^*}{(1+\tilde{t}_p')\,\hat{p}_e}\right) \\
&\quad + (1-\bar{j}')\left(\omega_c \frac{\hat{\pi}_c \hat{Y}}{(1+t_b')\,\hat{p}_e} + (1-\omega_c)\,\frac{\hat{\pi}_c^* \hat{Y}^*}{\hat{p}_e}\right) \\
&= \left(\frac{\bar{j}'}{1+\tilde{t}_p'} + 1 - \bar{j}'\right)\left(\omega_c \frac{\hat{\pi}_c \hat{Y}}{(1+t_b')\,\hat{p}_e} + (1-\omega_c)\,\frac{\hat{\pi}_c^* \hat{Y}^*}{\hat{p}_e}\right). \qquad (2)
\end{aligned}$$

We will exploit this equation below to substitute out terms involving changes in income.

We define *modified leakage* $\tilde{l}_P$ as the increased emissions in $\mathcal{F}$ resulting from a unilateral carbon tax in $\mathcal{H}$ relative to the resulting decline in global emissions. A value of $\tilde{l}_P > 0$ means that $\mathcal{F}$ has increased its emissions even as global emissions have declined due to the carbon tax in $\mathcal{H}$. Our leakage formula is thus:

$$\begin{aligned}
\tilde{l}_P &= \frac{\left(M_e^{HF'} + M_e^{FF'}\right) - \left(M_e^{HF} + M_e^{FF}\right)}{\left(M_e^{HH} + M_e^{FH} + M_e^{HF} + M_e^{FF}\right)(1-G)} \\
&= \frac{1}{1-G}\,\frac{M_e^{HF}\left(\hat{M}_e^{HF} - 1\right) + M_e^{FF}\left(\hat{M}_e^{FF} - 1\right)}{M_e^{HH} + M_e^{FH} + M_e^{HF} + M_e^{FF}} \\
&= \frac{1-\bar{j}}{1-G}\left(\omega_c \hat{M}_e^{HF} + (1-\omega_c)\,\hat{M}_e^{FF} - 1\right).
\end{aligned}$$

Leakage is driven by the proportional increase in $\mathcal{F}$'s use of energy in manufactures produced for its export market and in manufactures produced for its home market. Plugging these expressions into the leakage formula:

$$\tilde{l}_P = \frac{1-\bar{j}}{1-G}\left(\frac{1-\bar{j}'}{1-\bar{j}}\left(\omega_c \frac{\hat{\pi}_c \hat{Y}}{(1+t_b')\,\hat{p}_e} + (1-\omega_c)\,\frac{\hat{\pi}_c^* \hat{Y}^*}{\hat{p}_e}\right) - 1\right).$$

Plugging in (2), we get:

$$\tilde{l}_P = \frac{1-\bar{j}}{1-G}\left(\frac{1-\bar{j}'}{1-\bar{j}}\,\frac{G}{\frac{\bar{j}'}{1+\tilde{t}_p'} + 1 - \bar{j}'} - 1\right).$$

To simplify further, we can use:

$$\frac{1-\bar{j}'}{1-\bar{j}} = \frac{1}{\bar{j}\left(1+\tilde{t}_p'\right)^{-\theta(1-\gamma)} + 1 - \bar{j}}$$

and

$$\bar{j}' = \frac{\bar{j}\left(1+\tilde{t}_p'\right)^{-\theta(1-\gamma)}}{\bar{j}\left(1+\tilde{t}_p'\right)^{-\theta(1-\gamma)} + 1 - \bar{j}}$$

Incorporating these expressions:

$$\begin{aligned}
\tilde{l}_P &= \frac{1-\bar{j}}{1-G}\left(\frac{1}{\bar{j}\left(1+\tilde{t}_p'\right)^{-\theta(1-\gamma)} + 1 - \bar{j}} \frac{G}{1 - \frac{\tilde{t}_p'}{1+\tilde{t}_p'}\frac{\bar{j}\left(1+\tilde{t}_p'\right)^{-\theta(1-\gamma)}}{\bar{j}\left(1+\tilde{t}_p'\right)^{-\theta(1-\gamma)}+1-\bar{j}}} - 1\right) \\
&= \frac{1-\bar{j}}{1-G}\left(\frac{G}{\bar{j}\left(1+\tilde{t}_p'\right)^{-\theta(1-\gamma)}\left(1-\frac{\tilde{t}_p'}{1+\tilde{t}_p'}\right) + 1 - \bar{j}} - 1\right) \\
&= \frac{1-\bar{j}}{1-G}\left(\frac{G}{\bar{j}\left(1+\tilde{t}_p'\right)^{-\theta(1-\gamma)-1} + 1 - \bar{j}} - 1\right).
\end{aligned}$$

One implication is that, given G, leakage depends only on $\tilde{t}_p'$. Furthermore, leakage is monotonically increasing in $\tilde{t}_p'$. At the extreme of $\tilde{t}_p' = 0$, as under a full border tax adjustment, the leakage formula reduces to $-(1-\bar{j})$. Leakage is negative as $\mathcal{F}$ contibutes to reductions in global emissions in proportion to its initial share of those emissions.

2 Welfare

The ultimate goal of any carbon taxing scheme is to maximize welfare conditional on meeting emissions reduction criteria. In this model, a country's welfare is its spending power - more precisely, its income divided by a price index of energy, manufactures, and the l-good (see :

$$W = \frac{Y}{p}$$

After taxes, welfare can change, and we denote this as before with a hat:

$$\hat{W} = \frac{W'}{W}$$

These expressions are analogous for Foreign with stars. There is one more relevant measure which is world welfare. Since welfare can differ between Home and Foreign, world welfare is expressed in expectation, weighted by the sizes of the countries' respective labor forces:

$$W_{world} = \omega_L * W + \omega_L^\star * W^\star \tag{3}$$

where ω_L and $\omega_L^\star$ denote the world share of labor returns in Home and Foreign, respectively (recall that wages are equalized):

$$\omega_L = \frac{\pi_L * Y_{rel}}{\pi_L * Y_{rel} + \pi_L^\star} \tag{4}$$

$$\omega_L^\star = \frac{\pi_L^\star}{\pi_L * Y_{rel} + \pi_L^\star} \tag{5}$$

3 Changes in Production and Consumption of Energy

After imposing a tax, the value of the energy used in $\mathcal{H}$ to supply the domestic market is:

$$p_e' M_e^{HH\prime} = (1-\gamma)\,\bar{j}'\frac{\pi_c' Y'}{1+t_p'}$$

while for the foreign market:

$$p_e' M_e^{FH\prime} = (1-\gamma)\,\bar{j}'\frac{\pi_c^{*\prime} Y^{*\prime}}{1+\tilde{t}_p'}.$$

The value of the energy used in $\mathcal{F}$ to supply manufactures to $\mathcal{H}$ is:

$$p_e' M_e^{HF\prime} = (1-\gamma)\,(1-\bar{j}')\,\frac{\pi_c' Y'}{1+t_b'},$$

while in producing for $\mathcal{F}$:

$$p_e' M_e^{FF\prime} = (1-\gamma)\,(1-\bar{j}')\,\pi_c^{*\prime} Y^{*\prime}.$$

From these expressions, we can derive:

1. The post-tax change in Home production of energy:

$$
\begin{aligned}
(M_e^{HH} \hat{+} M_e^{HF}) &= \frac{M_e^{HH\prime} + M_e^{HF\prime}}{M_e^{HH} + M_e^{HF}} \\
&= \frac{\frac{(1-\gamma)\bar{j}' \frac{\pi_c' Y'}{1+t_p'}}{p_e'} + \frac{(1-\gamma)\bar{j}' \frac{\pi_c^{*\prime} Y^{*\prime}}{1+\tilde{t}_p'}}{p_e'}}{\frac{(1-\gamma)\bar{j}\pi_c Y}{p_e} + \frac{(1-\gamma)\bar{j}\pi_c^* Y^*}{p_e}} \\
&= \frac{\bar{j}'}{\hat{p}_e j} \frac{\pi_c' Y' + \pi_c^{*\prime} Y^{*\prime}(1+t_b')}{(\pi_c Y + \pi_c^* Y^*)(1+t_p')} \\
&= \frac{\bar{j}'}{\hat{p}_e j} \frac{\omega_c \hat{\pi_c} \hat{Y} + (1-\omega_c)\hat{\pi_c}^* \hat{Y}^* (1+t_b')}{1+t_p'}
\end{aligned}
$$

2. The post-tax change in Foreign production of energy:

$$
\begin{aligned}
(M_e^{HF} \hat{+} M_e^{FF}) &= \frac{M_e^{HF\prime} + M_e^{FF\prime}}{M_e^{HF} + M_e^{FF}} \\
&= \frac{1-\bar{j}'}{(1-j)\hat{p_e}} \frac{\omega_c \hat{\pi_c} \hat{Y}(1+t_b') + (1-\omega_c)\hat{\pi_c}^* \hat{Y}^*}{1+t_b'}
\end{aligned}
$$

3. The post-tax change in Home consumption of energy:

$$
\begin{aligned}
(M_e^{HH} \hat{+} M_e^{HF}) &= \frac{M_e^{HH\prime} + M_e^{HF\prime}}{M_e^{HH} + M_e^{HF}} \\
&= \frac{\hat{\pi_c}\hat{Y}}{\hat{p_e}} \left(\frac{\bar{j}'}{1+t_p'} + \frac{1-\bar{j}'}{1+t_b'} \right)
\end{aligned}
$$

4. The post-tax change in Foreign consumption of energy:

$$
\begin{aligned}
(M_e^{FH} \hat{+} M_e^{FF}) &= \frac{M_e^{FH\prime} + M_e^{FF\prime}}{M_e^{FH} + M_e^{FF}} \\
&= \frac{\hat{\pi_c}^* \hat{Y}^*}{\hat{p_e}} \left(\frac{\bar{j}'}{1+\tilde{t_p}'} + (1-\bar{j}') \right)
\end{aligned}
$$