Technical Appendix

Ilayda Dinc & Sara Orofino

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1. Marginal Cost of Abatement by Sector

Using the data provided, regression analysis is conducted to find the marginal cost of abatement curve for 4 different sectors. For the ease of later calculations, linear models are used for each sector. However, there might be better fitting functional forms. For example, for Sector C exponential function might fit better, and for Sector D quadratic function might fit better.

Sector A

$Marginal\ Cost\ Abatement\ Sector\ A = 0.5768419 * q + -8.6444767$

Sector B

$Marginal\ Cost\ Abatement\ Sector\ B = 0.1987443 * q + 9.3176977$

Sector C

$Marginal\ Cost\ Abatement\ Sector\ C = 0.7838266 * q + -11.6550307$

Sector D

For linear fit: $Marginal\ Cost\ Abatement\ Sector\ D = 0.2599275 * q + 9.6875061$

Quadratic fit for Sector D's marginal abatement cost is found to be: $Marginal\ Cost\ Abatement\ Sector\ D = -0.0437836 * q + 0.0020247 * q^2 + 16.774099$

The estimated marginal abatement cost functions in all four sectors are graphed below in Figure 1

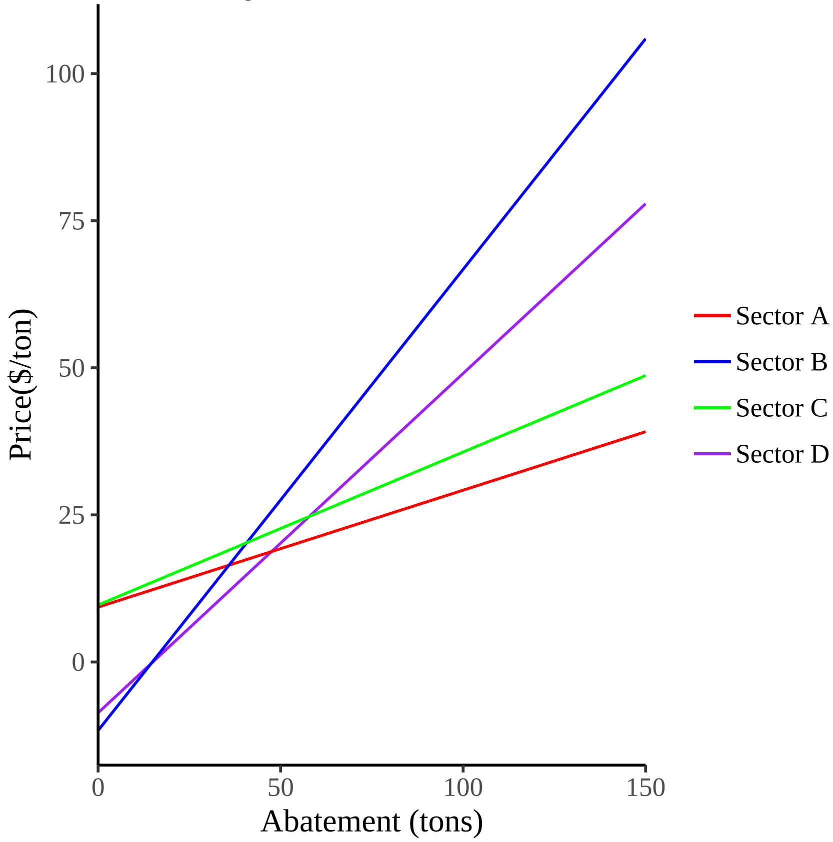

Figure 1: Marginal Abatement Cost Funtions of Four Sectors

2. Demand for Carbon Emissions

Demand Curves

Demand curve for carbon emissions is found for each sector by pluging in (Current Emission-q) for q in the marginal cost of abatement equation. The cost of abatement of quantity q is equal to willingness to pay for emitting (Current Emission-q).

In the new equation (demand curve), q will represent the amount of emissions. Plugging in O for q will result in the willingness to pay for the right to emit the first unit.

Sector A: $Price\ of\ Emissions = 0.5768419 * (180 - q) + -8.6444767$
- Willingness to Pay for First Unit = \$95.2

Sector B:

$Price\ of\ Emissions = 0.1987443 * (200 - q) + 9.3176977$

- Willingness to Pay for First Unit = \$49.12

Sector C:

$Price\ of\ Emissions = 0.7838266 * (220 - q) + -11.6550307$

- Willingness to Pay for First Unit = \$160.78

Sector D:

$Price\ of\ Emissions = 0.2599275 * (300 - q) + 9.6875061$

- Willingness to Pay with Linear Function: $87.69

$Price\ of\ Emissions = -0.0437836 * (300 - q) + 0.0020247 * (300 - q)^2 + 16.774099$

- Willingness to Pay for First Unit = $185.46

Note: The rest of the anlaysis will use the linear demand equations for each sector. But it is important to note that different functional forms result in different predictions for willingness to pay.

3. Country X

Suppose to meet the Paris Accord commitments, Country X (which contains sectors A, B, and C) needs to cut all carbon emissions in half.

a. Cap on Carbon

Marginal cost of abatement curves for each sector are used to calculate the total cost of abating by 100 tons. The area underneath the marginal cost of abatement curve from 0 to 100 gives the total cost of abatement for that sector. The arees are calculated by integration and the total cost of carbon cap is the sum of the costs of three sectors.

1. Total Cost of Carbon Cap

$Total\ Cost = 6698.88$

2. Cost/Benefits to each Sector

$Cost\ to\ Sector\ A = 2019.76$

$Cost\ to\ Sector\ B = 1925.49$

$Cost\ to\ Sector\ C = 2753.63$

3. Tax Revenue

There is no tax revenue with a carbon cap.

b. Tax on Carbon

To find the tax that accomplishes the desired reduction of 300, aggreagate marginal cost curve for 3 sectors in Country X is found. to find the aggregate cost, the marginal costs equations of 3 sectors are horizontally added. Marginal cost of 300th unit on the aggregate marginal cost curve is equal to the tax required.

$Optimal\ Carbon\ Tax = 39.43$

1. Total Cost of Carbon Tax

The total abatement cost is the area under the aggregate cost curve from 0 to 300.

$Total\ Abatement\ Cost\ of\ Carbon\ Tax = 5879.81$

2. Cost/Benefits to each Sector

Plugging in the marginal cost of abatement(the tax in this case) will result in the quantity abated by each sector. The areas underneath the marginal cost curves for each sector from 0 to the quantity abated will give the total cost of abatement for each sector. Each sector also pays tax for their emissions, so the amount of tax each sector pays is added to their total cost.

$Cost\ to\ Sector\ A = 5095.16$

$Cost\ to\ Sector\ B = 5604.46$

$Cost\ to\ Sector\ C = 7008.16$

3. Tax Revenue

Tax revenue is calculated by multiplying the total emissions by the amount of tax. Total emissions is found by subtracting the amount of abatement from the total initial emissions of 600 tons.

$Tax\ Revenue = 1.1827974 \times 10^4$

c. Cap and Trade

Even though they are initially allocated current emissions minus 100, cap and trade will satisfy the equal marginal principle and the total reduction of 300 will be distributed between the three sectors just like in the part b. The marginal cost of abatement will be equal for all sectors which is equal to the marginal cost of abatement of 300th unit on the aggregate cost curve.

1. Total Cost of Carbon Cap and Trade

The total cost of the cap and trade is the area under the aggregate cost curve from 0 to 300. The trades between sectors cancel each other.

$Total\ Cost\ Cap\ and\ Trade = 5879.81$

2. Cost/Benefits to each Sector

Firstly, The areas underneath the marginal cost curves for each sector from 0 to the quantity abated are calculated to find total cost of abatement for each sector. Then, depending on the trade, the quantity traded times the price is added (if bought) or subtracted (if sold) to find the total cost of Cap and Trade to each sector.

$Cost\ to\ Sector\ A = 1941.04$

$Cost\ to\ Sector\ B = 1661.8$

$Cost\ to\ Sector\ C = 2276.97$

3. Tax Revenue

There is no tax revenue with a cap and trade.

4. Country Y

Country Y contains only Sector D and is not obligated to reduce its emissions. To enter into Country X's carbon market Country Y would need to cap its emissions at its current level (300 tons) but allows them to sell credits to Sectors A, B, and C in Country X.

Sector D is also added to the aggregate marginal cost curve and abatement quantity of 300 is plugged into the equation. That will result in the marginal cost of 29.8 which is less than the marginal cost of abatement for Country X only (39.43). Then the total cost of abatement of 300 is calculated to be 4729.1 by adding up costs to each sector.

Also, total cost of international cap and trade to Country X is calculated as $5507.81, whereas total cost to Country Y is -778.71.

Incentives for Country Y to enter the carbon market:

The total cost of entering the market is negative for Country Y. It is cheaper for Sector D to reduce their emissions and the sectors in country X are willing to pay more than the cost of sector D.

Incentives for Country X to attract Country Y to the carbon market:

The total cost of cap and trade for Country X gets cheaper as Country Y enters the market. (It was $5879.81 for the cap and trade in only Country X). Sector D can reduce their emission cheaper than the sectors in

Country X. So, sectors in Country X will pay less to Country Y than the price it would normally cost to them to reduce emissions.

5. Local Air Pollution

Now assume every ton of carbon emissions creates one ton of local air pollution. Local air pollution only causes economic damages in the country where it is emitted. Neither Country X nor Country Y have local air pollution regulations.

a. Carbon Cap and Trade Market only Covering Country X

How much local air pollution would you expect in Country X and Country Y?

- If Cap and Trade is only covering Country X, Country X will be emitting 300 tons of carbon emissions and that will result in 300 tons of local air pollution.
- Since there is no cap and trade in Country Y, they will continue to emit at the same level as their current emissions which is 300 tons of carbon, and that will result in 300 tons of air pollution.

b. Country Y enters the Carbon Market of Country X

How much local air pollution would you expect in Country X and Country Y?

From the previous question, the abatement of Country Y is calculated as 77.39, if it enters the carbon market. Country X will be emitting 77.39 more, so the amount of air pollution will be 377.39.

Since Country Y will be abating their current emissions of 300 tons by 77.39, they will be emitting 222.61 tons of carbon, resulting in 222.61 tons of air pollution.

c. Advice on International Trade of Carbon Emission Credits

Allowing international trade of carbon emissions is economically efficient for both countries but the local impacts of carbon emissions is not captured by this model. If Country Y enters to the market, Country X will be emitting more carbon which will cause a lot of local air pollution.