Unit 5: Introduction to Cost-Benefit Analysis of Carbon Emissions Abatement

The far-reaching impacts (*harms or damages in economic* terms) of climate change will be costly to society. To avoid paying some of the projected costs, we must rapidly *abate* our emissions. **Abatement** is any action that reduces or otherwise counters the effects of GHG emissions. *Economist tend to use abate in much the same way climate scientists use mitigate.*

Abatement, like climate change damages, is also costly. This leads economists to seek a "sweet spot" between emitting and abating that is economically optimal (*or efficient*) because it maximizes overall well-being by balancing the emissions from the goods and services we consume with damages caused by those emissions. To find this "sweet spot", climate economists first estimate the benefits and the costs of abating and then set the target abatement where the difference between benefits and costs is largest. *Another way of saying this is to set the abatement target where the incremental (or marginal) benefit of abatement equals the incremental (or marginal) cost of abatement*

This worksheet guides you through the process of estimating the optimal level of abatement from webDICE model output.

A. Estimating benefit of abatement

Since abatement is the inverse of emissions, economists use the concept of avoided cost of emissions to estimate the benefit of abatement. Recall that in unit 3, we used webDICE to develop the social cost of carbon (SCC), which represents marginal (or incremental) damages from emissions. Under the Business as usual (BAU) scenario, Figure 1 below shows the SCC generated by webDICE.

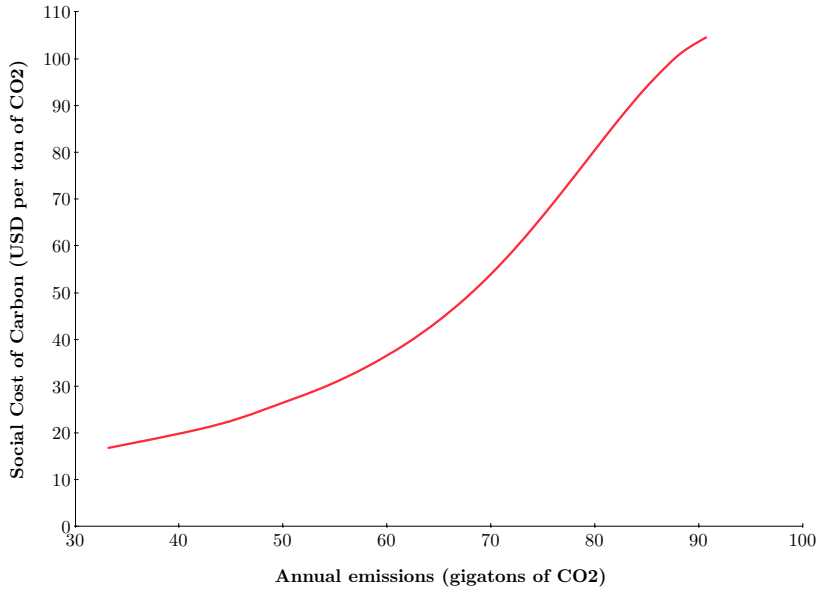

Figure 1: Social cost of carbon under Business as Usual

Current CO_2 emissions are approximately 36 gigatons per year. The x-axis in Figure 1, which ranges from 30 gigatons per year to 100 gigatons per year, essentially captures the SCC for emissions that start around current levels and projects it into the future.

Why do incremental damages increase with carbon emissions? This is because we can adapt to small changes in climate patterns but it becomes increasingly harder for us to adapt as the effect of climate change becomes more severe. For example, farmers might adopt new varieties of drought-tolerant seed of a particular crop if the extent of climate change is small but they would need to cultivate entirely different crops if temperatures or rainfall patterns changed more than moderately. In extreme cases, some farmers and entire communities might need to relocate themselves in order to adapt to significant changes in temperature of weather patterns.
Since we want to estimate the benefits of abatement starting from current emission levels and going down, we need to **extrapolate** the SCC for lower emission levels. Figure 2 shows the extended SCC (dashed red shows extrapolation with the spline function in Matlab).

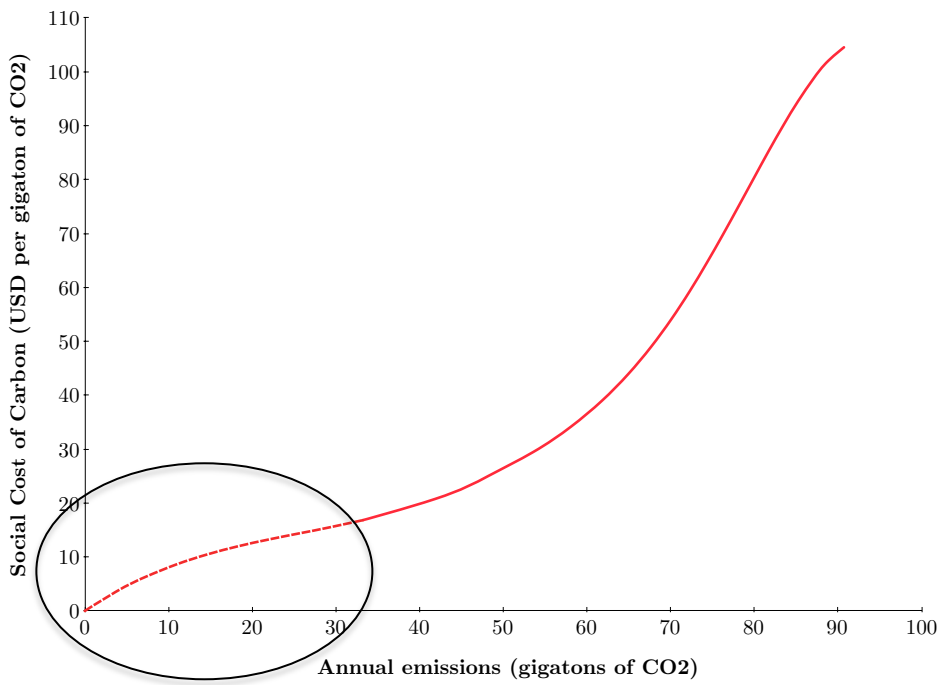

Figure 2: Social cost of carbon under BAU scenario (extrapolated)

Figure 2 shows that, at the current level of emissions of 36 gigatons per year, the monetary value of the damage caused by an additional ton is about $18. Thus, if we abate 1 ton of carbon, we will avoid damages worth $18. Likewise, at 35 gigatons per year, the monetary value of the damage caused by an additional ton is about $17.50. Thus, if we were emitting 35 gigatons annually and abated another ton of carbon, we would avoid damages worth $17.50. This is the marginal abatement benefit at the current level of emissions.

*The **marginal abatement benefit** is the reduction in the social cost of carbon when carbon emissions are abated by one ton.*

Repeating this process at various levels of abatement, one can generate the relationship between the amount of CO_2 abated and its marginal benefit. This relationship is shown in Figure 3, which is essentially the mirror image of the circled portion in Figure 2.

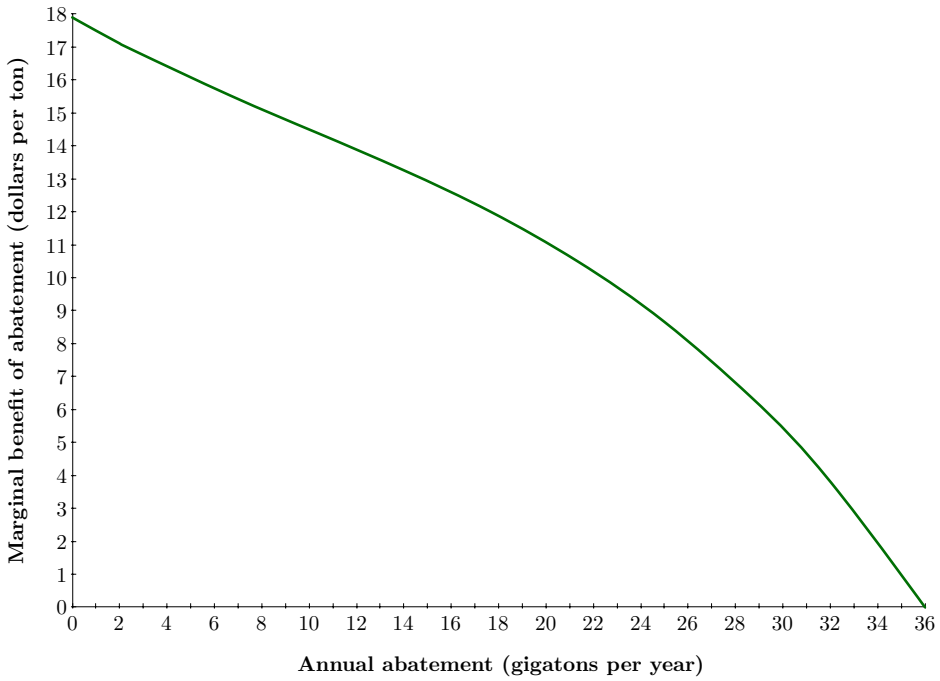

Figure 3: Marginal abatement benefit under BAU scenario

Review questions

1. How much is the marginal abatement benefit at 22 gigatons of abatement (or 14 gigatons of emissions)?
2. How much is the marginal abatement benefit at 14 gigatons of abatement (or 22 gigatons of emissions)?
3. Why is marginal abatement benefit at 36 gigatons of abatement equal to zero?

Answers: 1. About $10. 2. About $13. 3. Because that is complete abatement and so emissions and damages go down to zero.

B. Estimating cost of abatement

*The **marginal abatement cost** is the cost of reducing carbon emissions by one ton.*

To mitigate the impacts of climate change, we need to deploy various technologies, such as

switching from incandescent to LED bulbs to produce more light per ton of emissions (for other examples, see Exhibit 1 in the "Summary of Findings" in McKinsey 2009). The costs associated with such a switch include the investment in R&D in LEDs, the precious material required to make them, marketing and sales, etc. All of this imposes costs on communities.

Thus, the marginal abatement cost (or MAC) curve shows the relationship between the level of abatement and the incremental cost of reducing an additional unit of carbon.
Let us construct a MAC using a simple example (note: you will also do this during a class activity). Suppose that the United States has three actions it can undertake to abate its emissions. The table below lists each of these, along with their abatement potential and cost.

Abatement Actions	**Abatement Potential (Million tons of carbon)**	**Total Cost of Abatement (Billions $)**
Switch to Efficient Machinery	60	12
Reforestation	40	20
Replace coal-fueled power plants	120	30

1. **Calculate the average cost of abatement for each action.**
   Divide the Total Cost of Abatement by the Abatement Potential for each action. This yields the Average Cost of Abatement.

Abatement Actions	**Abatement Potential (Million tons of carbon)**	**Average Cost of Abatement ($ per ton)**
Switch to efficient machinery	60	200
Reforestation	40	500
Replace coal-fueled power plants	120	250

2. **Sort by increasing Average Cost.**
   The three actions are sorted so that the cheapest abatement actions are taken before the more expensive actions.

Abatement Actions	**Abatement Potential (Million tons of carbon)**	**Average Cost of Abatement ($ per ton)**
Switch to efficient machinery	60	200
Replace coal-fueled power plants	120	250
Reforestation	40	500

3. Calculate the cumulative emissions reduction.
   Doing so, we get the following table.

Abatement Actions	**Cumulative Abatement**

	Potential (Million tons of carbon)
Switch to efficient machinery only	60
Efficient Machinery + Replace coal plants	180
Efficient Machinery + Replace coal plants + Reforestation	220

4. Graph the MAC.

Next we plot the average cost of reduction against the cumulative emissions reduction obtained in step 3.

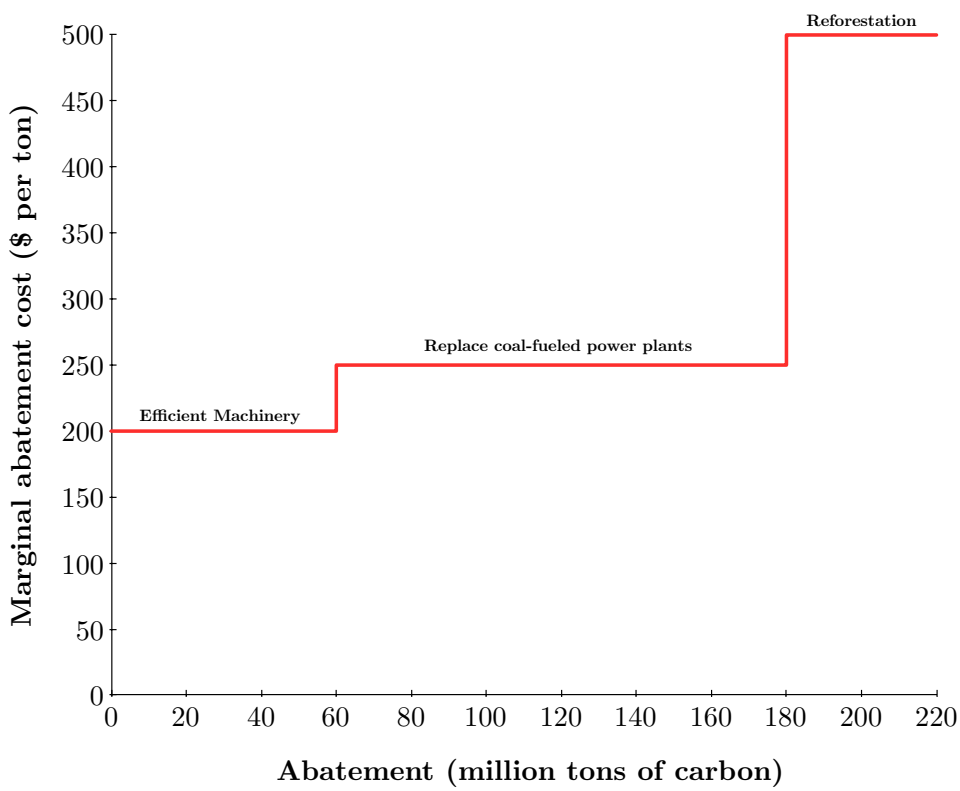

Figure 4: Marginal abatement cost

The MAC in Figure 4 shows that the first 60 million tons of carbon can be abated at a cost of $200 per ton (by switching to efficient machinery), an additional 120 millions tons can be abated at a cost of $250 per ton (by replacing coal-fired power plants), and another 40 million tons of carbon can be abated (through reforestation) at a cost of $500 per ton.

C. Calculating total cost of abatement

The total cost of abating any amount of carbon (up to 220 million tons in this example) can be calculated by computing the area under the marginal abatement cost curve. For example, the total cost of abating 80 million tons of carbon is $17 billion ($200 x 60 million + $250 x 20 million). This area is shown as the shaded red area under the MAC below.

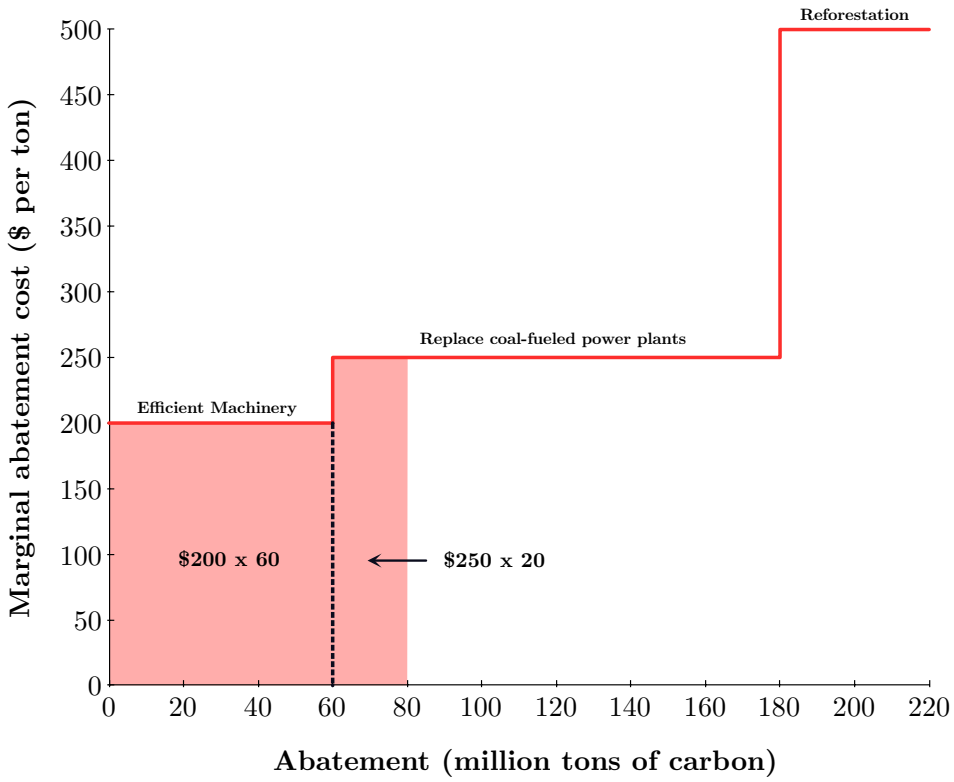

Figure 5: Calculating total abatement cost

Global MAC

McKinsey & Company, a well-known consulting group, has estimated the marginal abatement cost curve for the planet as a whole, which is reproduced below in figure 6.

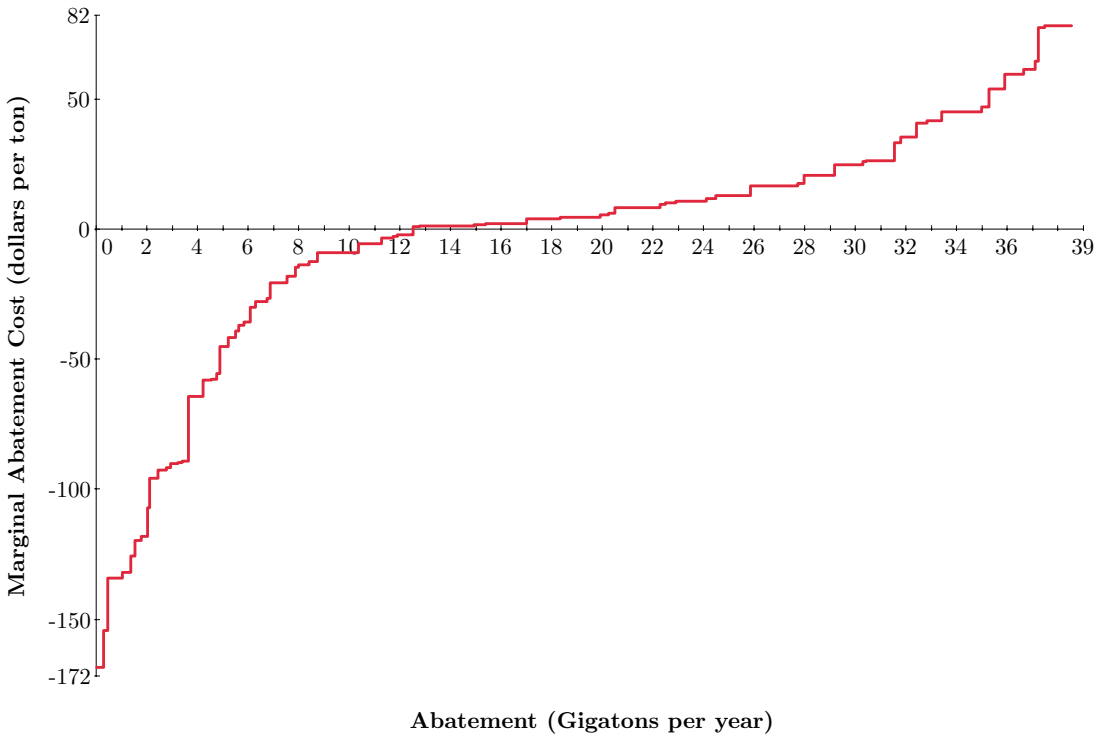

Figure 6: Global marginal abatement cost curve

This figure shows that the cost abating the first 13 gigatons of emissions is negative. This means taking these actions will actually allow us to *save* money! For example, when we switch from incandescent bulbs to LED bulbs, not only do we save energy but also emit less carbon and save money, even in the very short run. Other money-saving options include retrofitting homes to make them more energy efficient, developing hybrid cars and reducing waste and recycling more (see Exhibit 1 in the "Summary of Findings" in McKinsey (2009) for additional examples).

The total savings from abating the first 13 gigatons of emissions can be calculated by estimating the area between the x-axis and the MAC for abatement levels between zero and 13 gigatons, which is shown as the light green shaded area in Figure 7. The incremental cost of abating emissions after the 13th gigaton becomes positive. We can estimate the total cost of abating emissions between 13 and 36 gigatons, shown as the pink shaded area in figure 7. Interestingly, the sizes of the two areas are about the same, which leads to the following observation:

Theoretically, the abatement of all 36 gigatons of emissions would have a net cost of approximately zero!

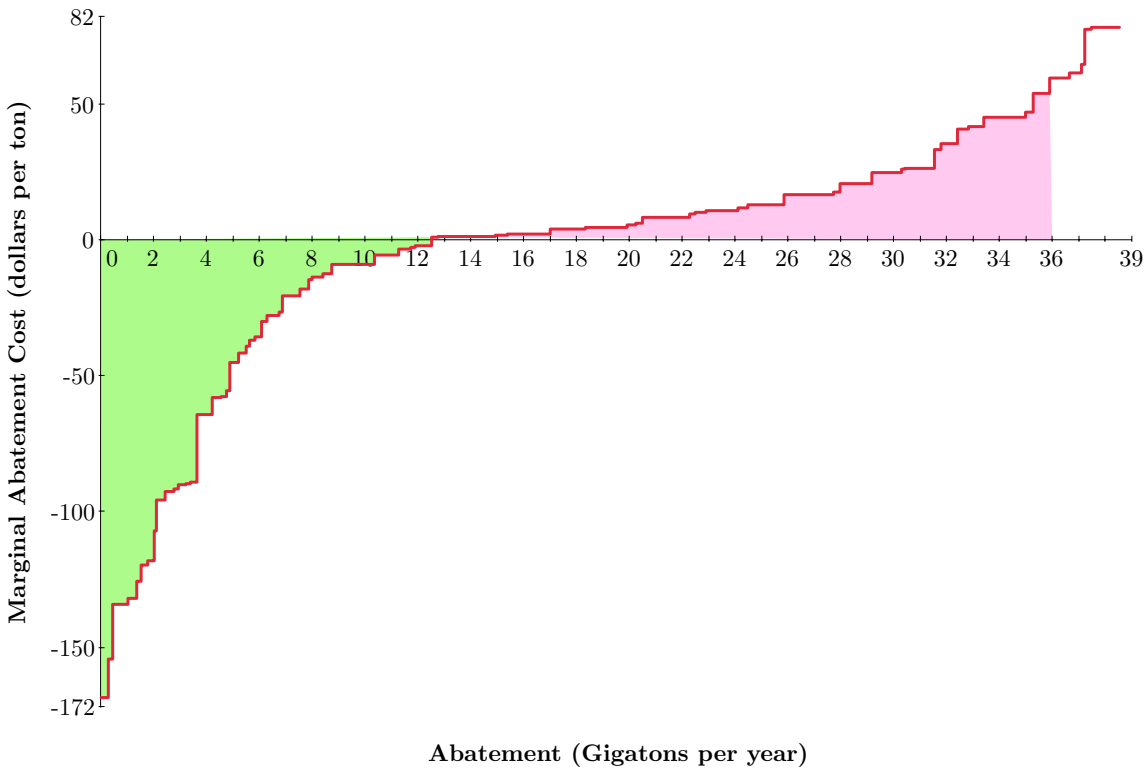

Figure 7: Net Cost of Abating 36 Gigatons

D. Optimal Abatement Level and Cost

Figure 8 superimposes the marginal abatement benefit and the marginal abatement cost that we've already seen and zooms in to evaluate their point of intersection. At any amount of abatement less than 22 gigatons, the benefit of abating an additional ton exceeds its cost; thus, it is beneficial to increase abatement by an additional ton. Likewise, at any amount of abatement greater than 22 gigatons, the cost of abating an additional ton exceeds its benefit; thus, it is beneficial to reduce abatement by an additional ton.

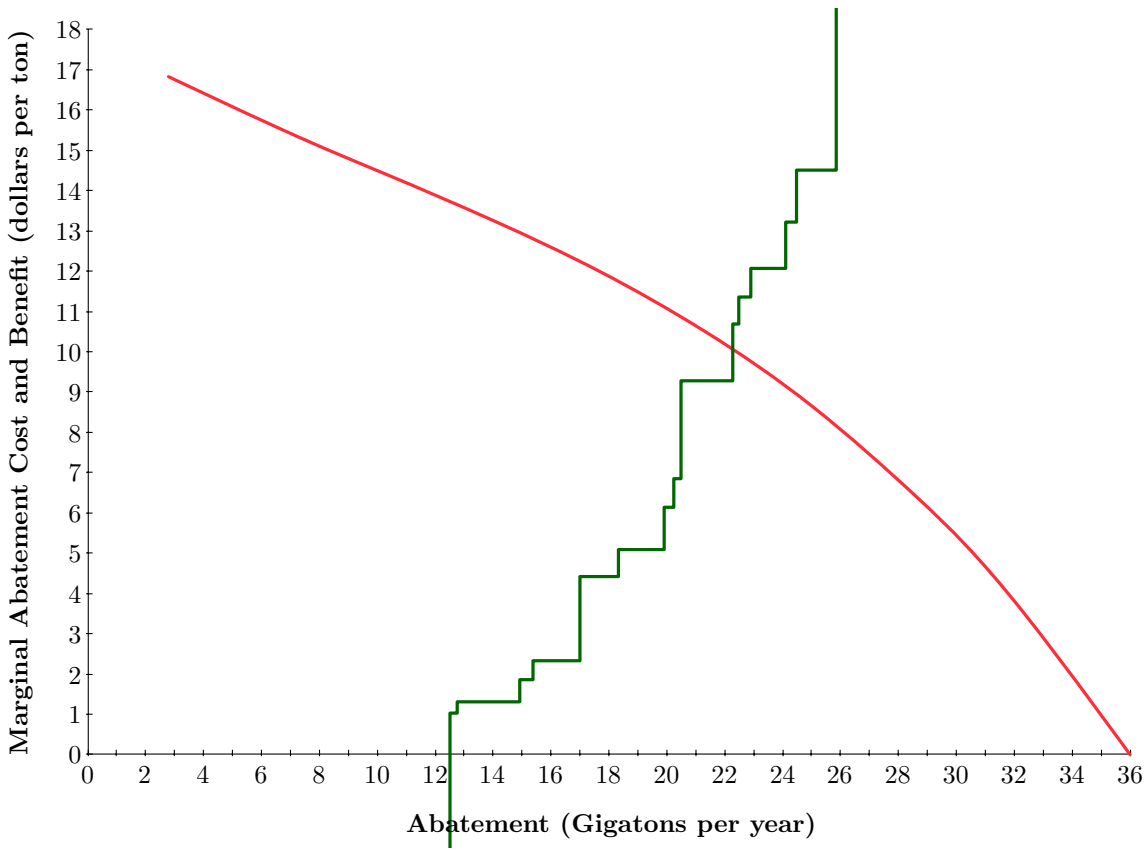

Figure 8: Determining Optimal Abatement

The economically optimal abatement amount is where the marginal abatement benefit equals its marginal cost, or 22 gigatons based upon the data used here. This is over 60% of current emissions.

The height of the marginal benefit curve (y-axis) at 22 gigatons (x-axis) is the economic benefit of abating the 22nd gigaton. This height is about $10 per ton. Recall, this may also be interpreted as the marginal damage from emitting the 22nd gigaton. Thus, if we were to invoke the polluter pays principle, we should charge polluters approximately $10 per ton. To contextualize this number, the price of permits in the European Union's Emissions Trading Scheme (EU ETS) has been hovering between €5 and €9 (approximately $5.50 and $10) over the last several years.