# Economics of Climate Change – Final Exam

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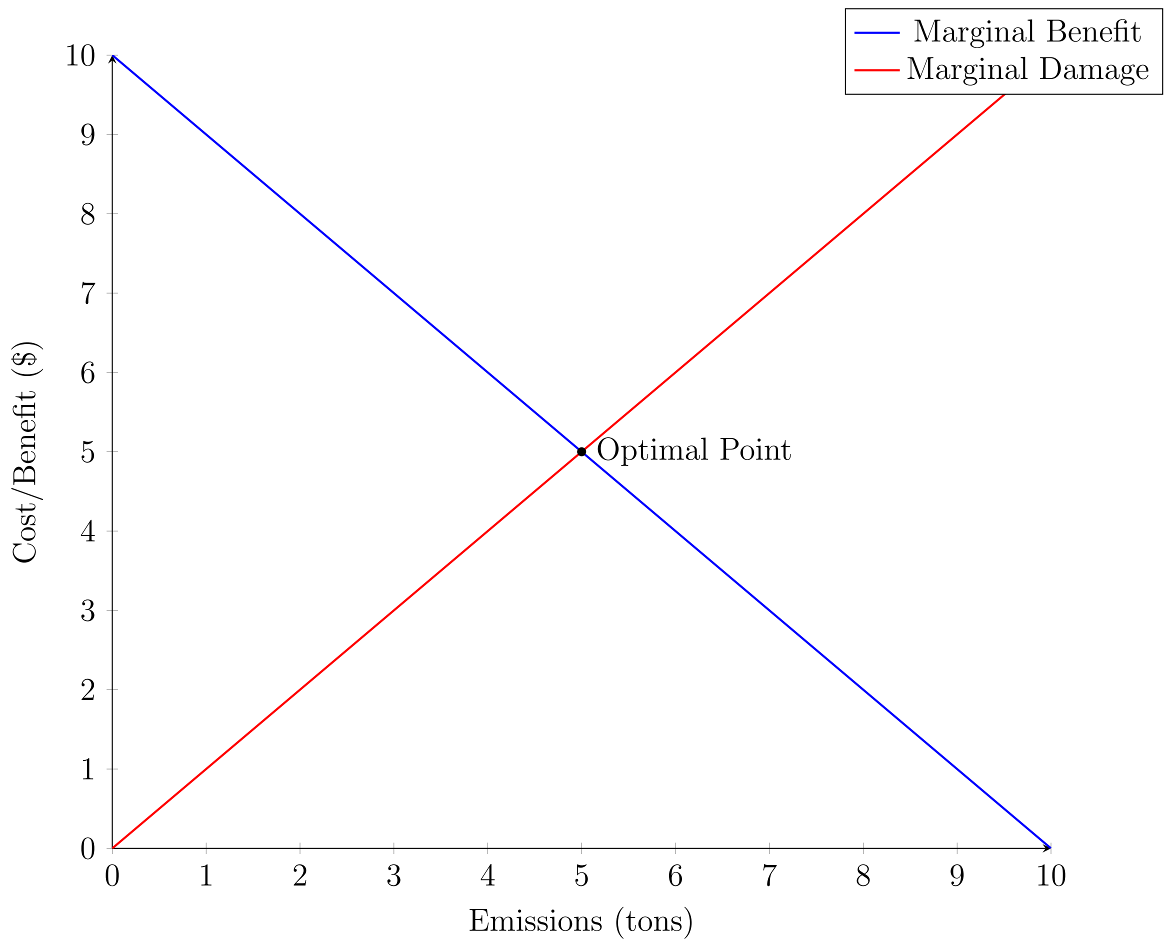
## 1 Short Answer




### 1.1

The socially optimal level of pollution occurs where the marginal benefit of emitting one additional unit of GHG equals the marginal damage from that emission. At this point, the net benefit to society from emissions is maximized, balancing economic activity and environmental impact.

### 1.2 Arguments for IAMs:

(a) IAMs combine scientific and economic insights to provide a comprehensive framework for estimating the social cost of carbon. This allows policymakers at all levels to understand trade-offs between environmental protection and economic growth, and make informed decisions.

(b) IAMs provide quantitative outputs that help governments design policies like carbon taxes or emission caps, providing a data proofed approach to climate mitigation.

**Arguments against IAMs:**

(a) The results of IAMs can vary significantly based on inputs such as discount rates, damage functions, and emission scenarios, leading to potentially unreliable estimates.

(b) IAMs often oversimplify key climate and economic processes, such as feedback loops and tipping points, which undermines their ability to capture the full scope of climate impacts.

### 1.3 Why a Low Discount Rate is Critical for Climate Policy

I strongly advocate for a low discount rate—specifically 1.5%—when evaluating climate change impacts. A low discount rate highlights the moral imperative of valuing future generations' well-being on par with our own.

Climate change poses risks that span centuries, from rising sea levels to biodiversity loss. A higher discount rate diminishes the present value of these future damages, potentially leading to underinvestment in mitigation efforts today. By adopting a low discount rate, we can emphasize the importance of addressing long-term challenges.

The choice of discount rate is fundamentally an ethical decision. A low rate ensures that future generations—who will bear the brunt of our decisions—are not unfairly disadvantaged. It acknowledges their right to inherit a stable and sustainable world, placing value into the future of the world.

Critics may argue that a lower discount rate could slow economic growth due to higher upfront costs. However, this perspective underestimates the catastrophic consequences of delayed action. Investing in mitigation and adaptation now will safeguard both our planet and economy for the long term.

The stakes are too high to discount the future. Let us choose a path that prioritizes sustainability and intergenerational fairness by committing to a low discount rate.

# 2 True/False/Uncertain with Justification

**2.2** **True.** The prisoner's dilemma illustrates the incentives to free ride because each country benefits from global GHG reductions regardless of its own contributions. Without cooperation, countries may prioritize short-term national benefits over long-term global gains, leading to underprovision of GHG abatement.

**2.3** **True.** Tipping points introduce nonlinear feedbacks that substantially increase the potential damages from climate change. Ignoring these in economic models underestimates the SCC, and including them often doubles or even triples the estimates.

**2.4** **True.** Carbon taxes are regressive because energy expenditures constitute a larger portion of low-income households' budgets.

**2.5** **Uncertain.** While global coordination is critical for addressing large-scale emissions, individual behavior changes, such as reducing energy consumption, can cumulatively make a significant impact. However, simply making these changes with nothing else is still insufficient without systemic policies.

**2.7** **Uncertain.** Rapid elimination of GHG emissions would significantly reduce risks of tipping points, but some may already be unavoidable due to historical emissions. The effectiveness depends on the specific tipping points and their sensitivity to current conditions.

# 3 Carbon tax on gasoline

**3.1** SCC values (in dollars per metric ton of $CO_2$):

- SCC at 1.5% discount rate = 340 \$/metric ton
  Carbon Tax $= 340 \times 0.00883 = 3.002$ \$/gallon
- SCC at 2.0% discount rate = 190 \$/metric ton
  Carbon Tax $= 190 \times 0.00883 = 1.678$ \$/gallon

- SCC at 2.5% discount rate = 120 \$/metric ton

  Carbon Tax = $120 \times 0.00883 = 1.060$ \$/gallon

The carbon tax per gallon of gasoline for each discount rate:

- **1.5% discount rate:** \$3.00/gallon
- **2.0% discount rate:** \$1.68/gallon
- **2.5% discount rate:** \$1.06/gallon

The carbon tax per gallon increases with lower discount rates, reflecting the higher valuation of future climate damages.

**3.2**

$$7 - \frac{g}{40} = 3 + \frac{g}{200}.$$

$$4 = \frac{g}{40} + \frac{g}{200}.$$

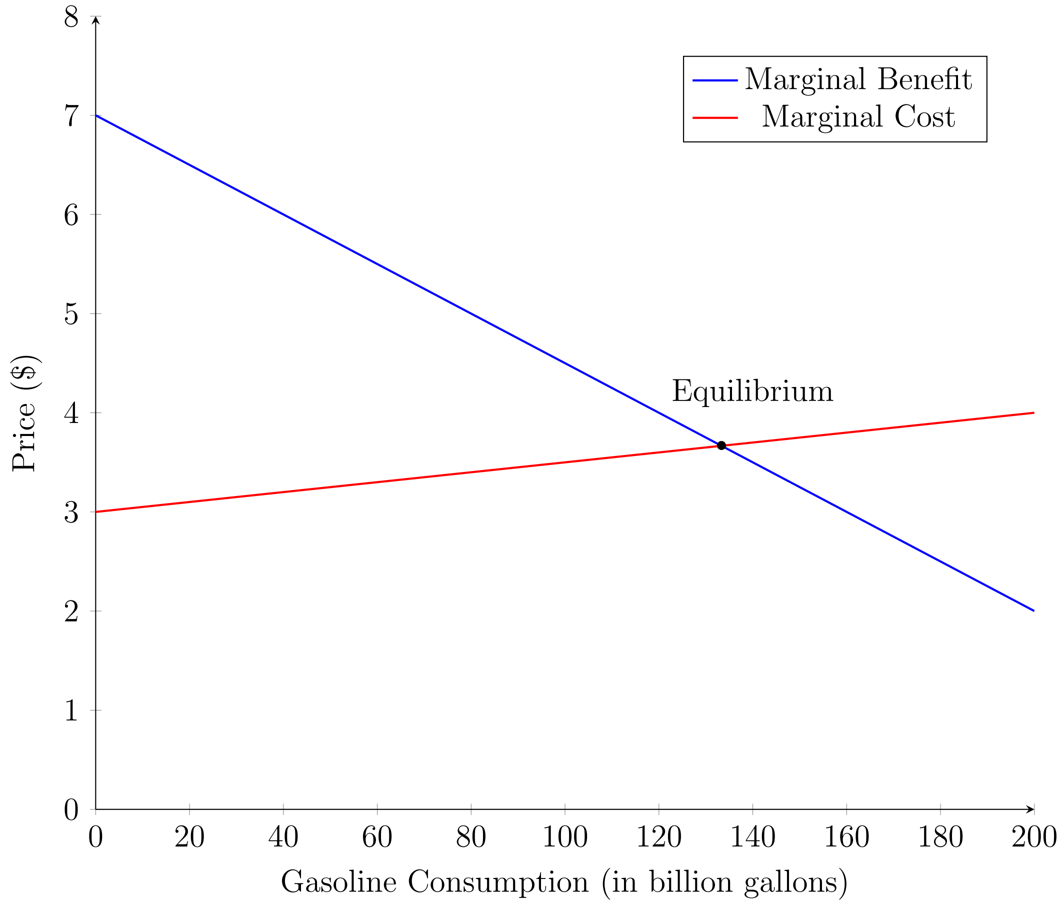
$$4 = \frac{5g + g}{200} = \frac{6g}{200}.$$

$$g = \frac{4 \cdot 200}{6} = 133.33\,\text{billion gallons}$$

$$\text{Price} = 7 - \frac{133.33}{40} = 3.67\,\$/\text{gallon}$$

**Private Equilibrium:**

- **Quantity:** 133.33 billion gallons
- **Price:** \$3.67 per gallon




**3.3** The SMC curves become:

- For 1.5%: $\text{SMC}_{1.5\%} = 3 + \frac{g}{200} + 3.00 = 6 + \frac{g}{200}$
- For 2.0%: $\text{SMC}_{2.0\%} = 3 + \frac{g}{200} + 1.68 = 4.68 + \frac{g}{200}$
- For 2.5%: $\text{SMC}_{2.5\%} = 3 + \frac{g}{200} + 1.06 = 4.06 + \frac{g}{200}$

**3.4** The socially optimal quantity occurs where MB = SMC.

**1.5% Discount Rate**

$$7 - \frac{g}{40} = 6 + \frac{g}{200}.$$

$$1 = \frac{g}{40} + \frac{g}{200}.$$

$$1 = \frac{5g + g}{200} = \frac{6g}{200}.$$

$$g = \frac{1 \cdot 200}{6} = 33.33\,\text{billion gallons}$$

**2.0% Discount Rate**

$$7 - \frac{g}{40} = 4.68 + \frac{g}{200}.$$

$$2.32 = \frac{g}{40} + \frac{g}{200}.$$

$$2.32 = \frac{5g + g}{200} = \frac{6g}{200}.$$

$$g = \frac{2.32 \cdot 200}{6} = 77.33 \, \text{billion gallons}$$

**2.5% Discount Rate**

$$7 - \frac{g}{40} = 4.06 + \frac{g}{200}.$$

$$2.94 = \frac{g}{40} + \frac{g}{200}.$$

$$2.94 = \frac{5g + g}{200} = \frac{6g}{200}.$$

$$g = \frac{2.94 \cdot 200}{6} = 98.00 \, \text{billion gallons}$$

The socially optimal quantities of gasoline consumption are:

- **1.5% discount rate:** 33.33 billion gallons
- **2.0% discount rate:** 77.33 billion gallons
- **2.5% discount rate:** 98.00 billion gallons

**3.5**

- For 1.5%: Tax $= 3.00 \, \$/\text{gallon}$, $g = 33.33 \, \text{billion gallons}$

  Revenue $= 3.00 \times 33.33 = 100.00 \, \text{billion dollars}$
- For 2.0%: Tax $= 1.68 \, \$/\text{gallon}$, $g = 77.33 \, \text{billion gallons}$

  Revenue $= 1.68 \times 77.33 = 129.91 \, \text{billion dollars}$
- For 2.5%: Tax $= 1.06 \, \$/\text{gallon}$, $g = 98.00 \, \text{billion gallons}$

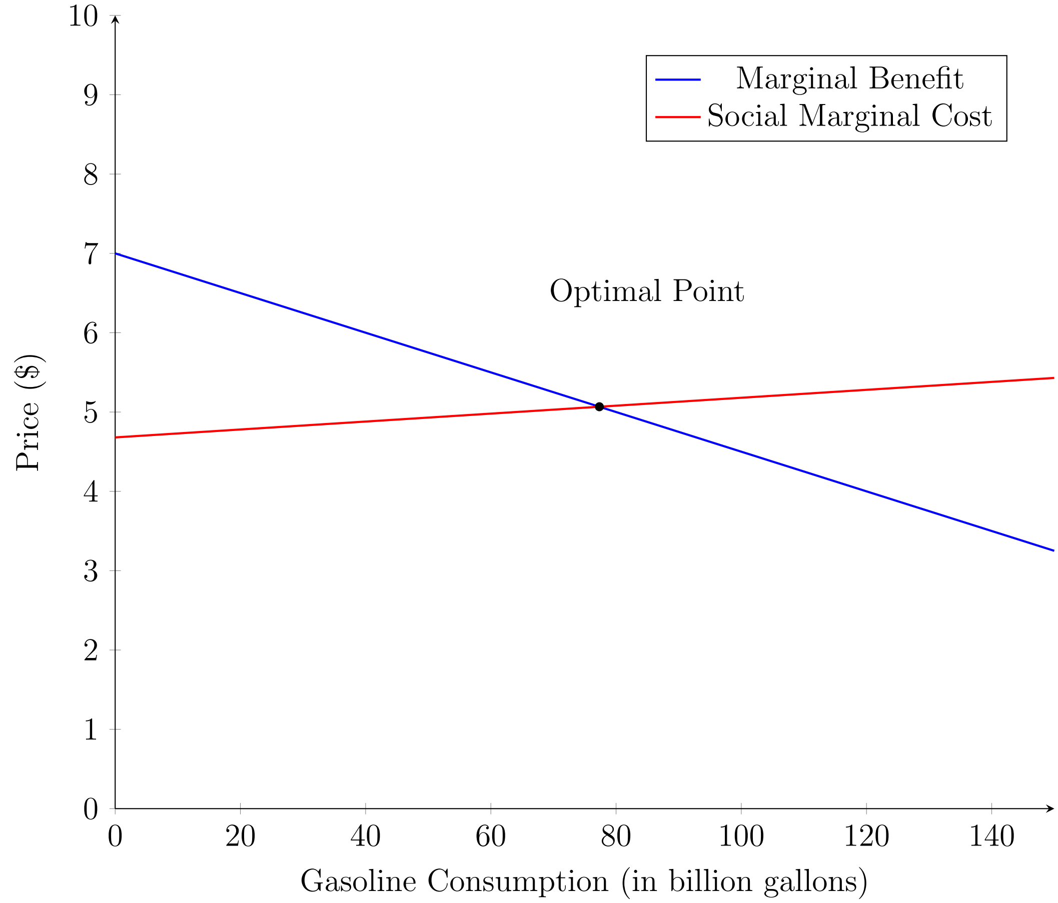
  Revenue $= 1.06 \times 98.00 = 103.88 \, \text{billion dollars}$

The total tax revenue for each discount rate is:

- **1.5% discount rate:** \$100.00 billion
- **2.0% discount rate:** \$129.91 billion
- **2.5% discount rate:** \$103.88 billion

**3.6** The SMC curve for the 2.0% discount rate is:

$$\text{SMC}_{2.0\%} = 4.68 + \frac{g}{200}.$$



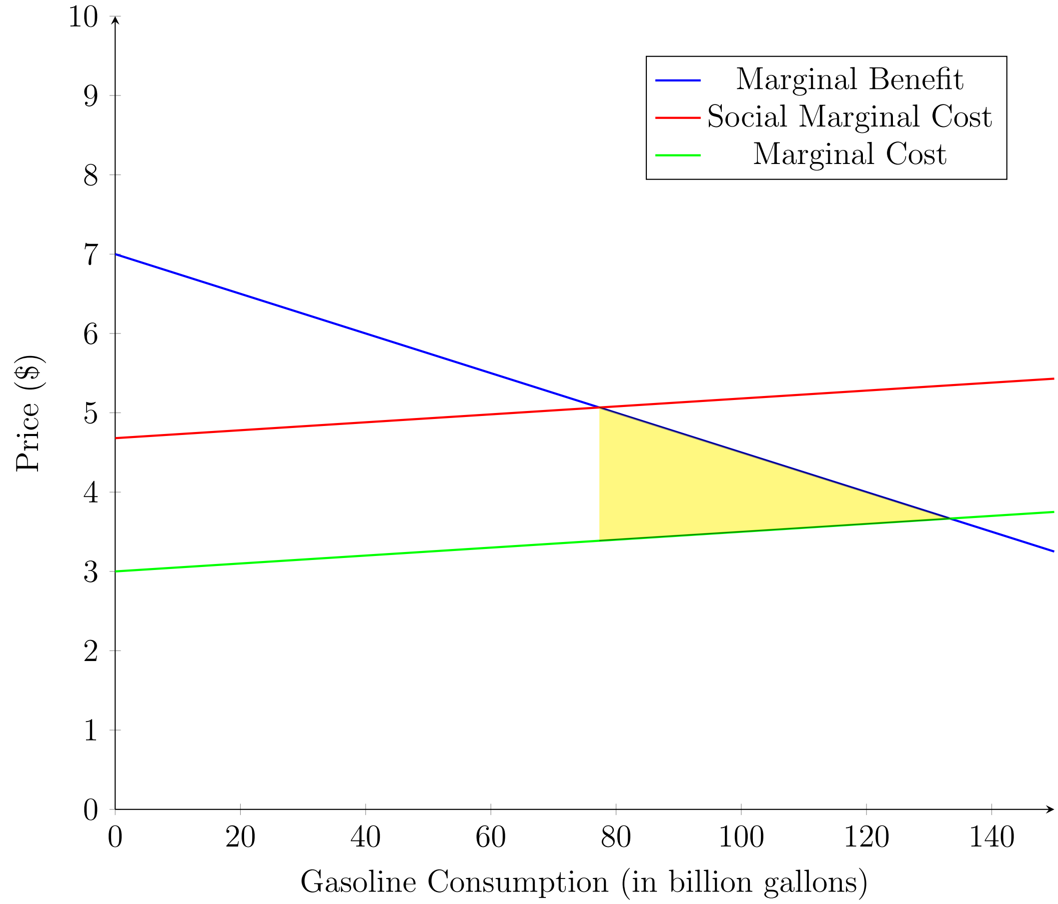

**3.7**

$$\text{DWL} = \frac{1}{2} \times (\text{Quantity Difference}) \times (\text{Price Difference})$$

- Private equilibrium quantity: $g_{\text{private}} = 133.33$ billion gallons
- Socially optimal quantity: $g_{\text{optimal}} = 77.33$ billion gallons
- Price difference: $\Delta P = 6.05 - 5.07 = 0.98$ \$/gallon

The DWL is:

$$\text{DWL} = \frac{1}{2} \times (133.33 - 77.33) \times 0.98 = \frac{1}{2} \times 56 \times 0.98 = 27.44 \text{ billion dollars}$$




**3.8** The price consumers pay is the Social Marginal Cost at the socially optimal quantity:

$$\text{Price Consumers Pay} = 5.07\,\$/\text{gallon}.$$

The price producers receive is the Marginal Cost at the socially optimal quantity:

$$\text{MC} = 3 + \frac{g_{\text{optimal}}}{200} = 3 + \frac{77.33}{200} = 3.39\,\$/\text{gallon}.$$

**3.9** The total tax revenue is split between consumers and producers based on the price they pay and receive, respectively.

- Consumer price: $P_{\text{consumer}} = 5.07\,\$/\text{gallon}$
- Producer price: $P_{\text{producer}} = 3.39\,\$/\text{gallon}$
- Socially optimal quantity: $g_{\text{optimal}} = 77.33\,\text{billion gallons}$
- Tax per gallon: $\text{Tax} = P_{\text{consumer}} - P_{\text{producer}} = 5.07 - 3.39 = 1.68\,\$/\text{gallon}$

The consumer tax burden:

$$\text{Consumer Tax Burden} = \text{Consumer Price} \times \text{Quantity}$$

$$\text{Consumer Tax Burden} = (5.07 - 3.39) \times 77.33 = 1.68 \times 77.33 = 129.91\,\text{billion dollars}$$

The producer tax burden:

$$\text{Producer Tax Burden} = \text{Producer Price} \times \text{Quantity}$$

$$\text{Producer Tax Burden} = 3.39 \times 77.33 = 262.15\,\text{billion dollars}$$

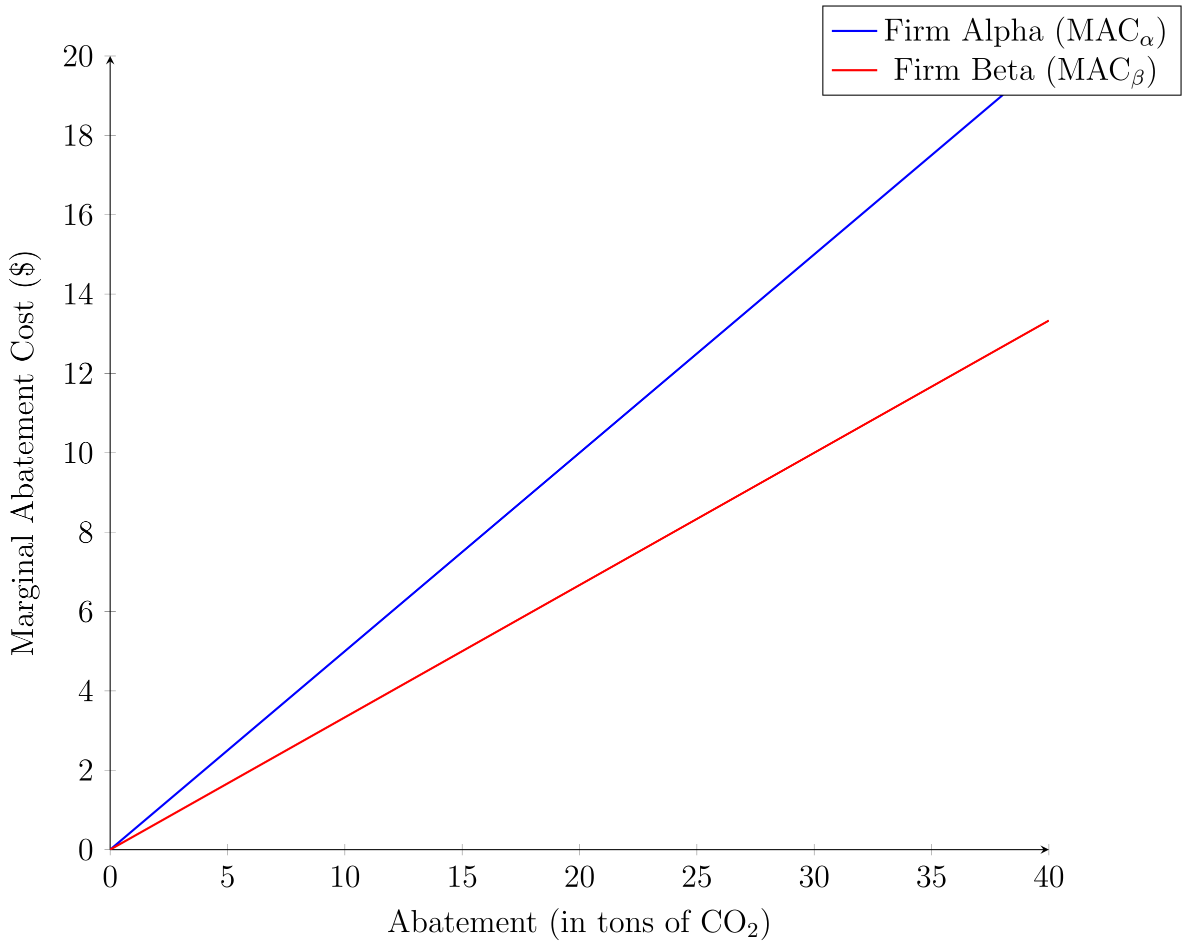
- **Consumer Tax Burden:** \$129.91 billion
- **Producer Tax Burden:** \$262.15 billion

**3.10** The tax burden is higher for producers (\$262.15 billion) compared to consumers (\$129.91 billion). This is because the marginal cost curve is relatively flat compared to the marginal benefit curve, leading producers to bear more of the tax burden due to their inability to pass the full cost increase onto consumers. Producers bear a greater share of the tax burden because they supply gasoline at a relatively low marginal cost. Consumers face a smaller increase in price, reflecting their relatively higher sensitivity to price changes (elasticity of demand). Overall, the tax redistributes income between consumers, producers, and government revenue while addressing the externality of carbon emissions.

# 4 $CO_2$ Abatement

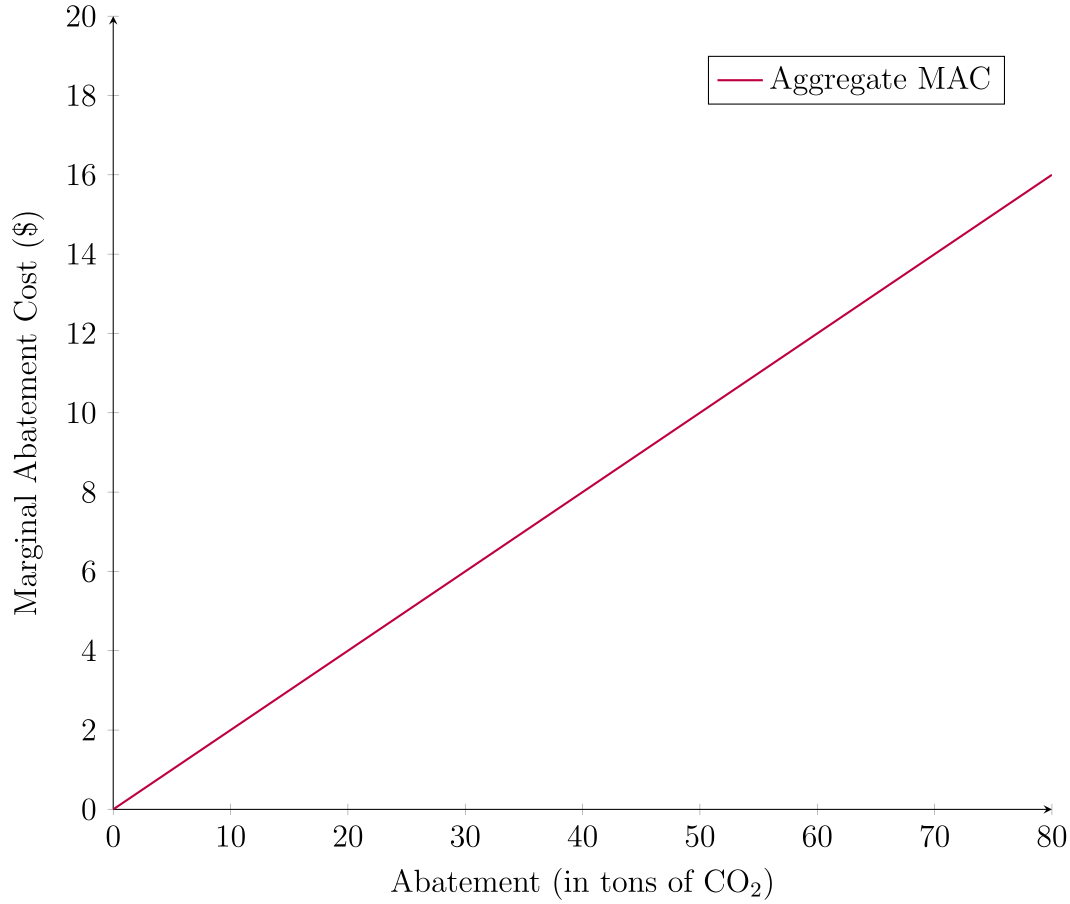
**4.1** (a) The marginal abatement cost functions for each firm are:

- Firm Alpha: $\text{MAC}_\alpha = \frac{A_\alpha}{2}$
- Firm Beta: $\text{MAC}_\beta = \frac{A_\beta}{3}$




(b) The aggregate MAC curve:

- The total abatement $A = A_\alpha + A_\beta$
- $A_\alpha = 2 \times \text{MAC}, \quad A_\beta = 3 \times \text{MAC}$
- Aggregate abatement: $A = A_\alpha + A_\beta = 2 \times \text{MAC} + 3 \times \text{MAC} = 5 \times \text{MAC}$
- $\text{MAC} = \frac{A}{5}$




**4.2** (a) The EPA policy requires each firm to reduce emissions by 6 tons of $CO_2$. Each firm's marginal abatement cost is calculated at this abatement level:

- For Firm Alpha:

$$\text{MAC}_\alpha = \frac{A_\alpha}{2} = \frac{6}{2} = 3\,\$/\text{ton}$$

- For Firm Beta:

$$\text{MAC}_\beta = \frac{A_\beta}{3} = \frac{6}{3} = 2\,\$/\text{ton}$$

(b)

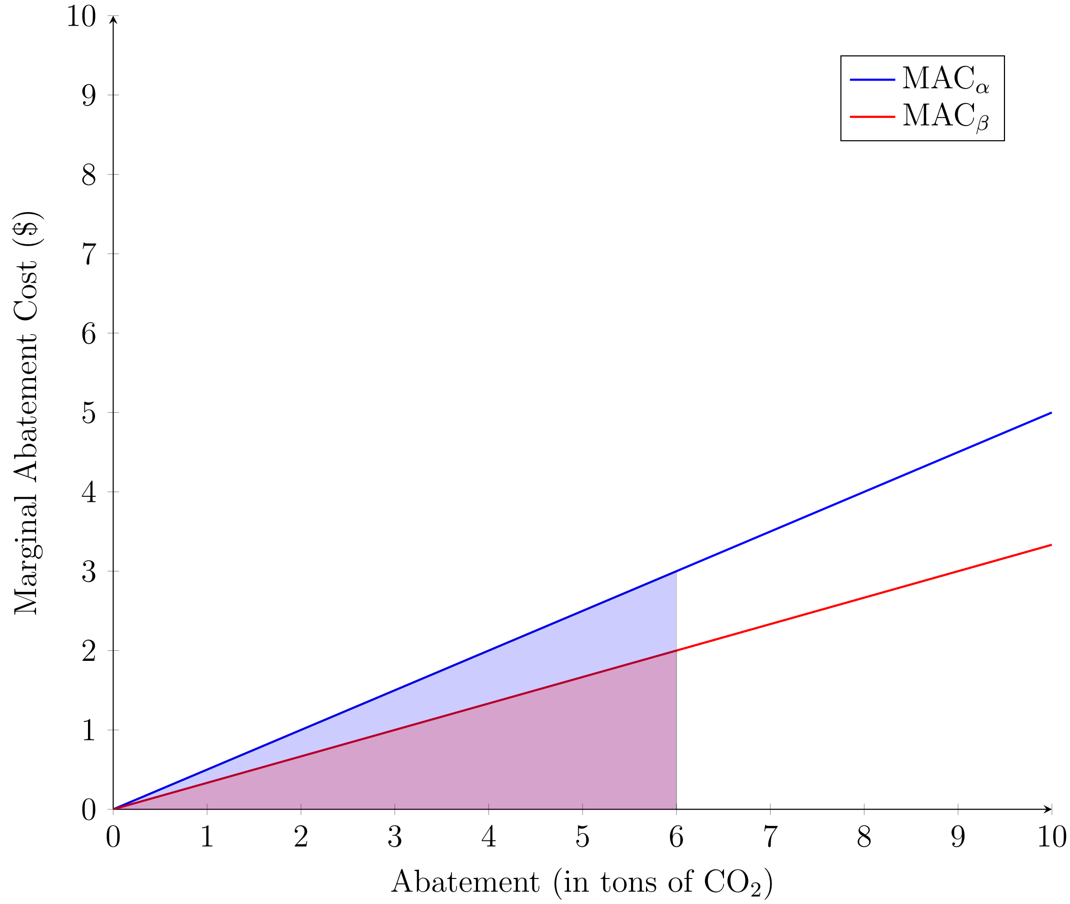
$$\text{TAC} = \int_0^A \text{MAC}\,dA$$

- For Firm Alpha:

$$\text{TAC}_\alpha = \int_0^6 \frac{A_\alpha}{2}\,dA_\alpha = \frac{1}{2}\int_0^6 A_\alpha\,dA_\alpha = \frac{1}{2}\left[\frac{A_\alpha^2}{2}\right]_0^6 = \frac{1}{2}\left(\frac{6^2}{2}\right) = \$9$$

- For Firm Beta:

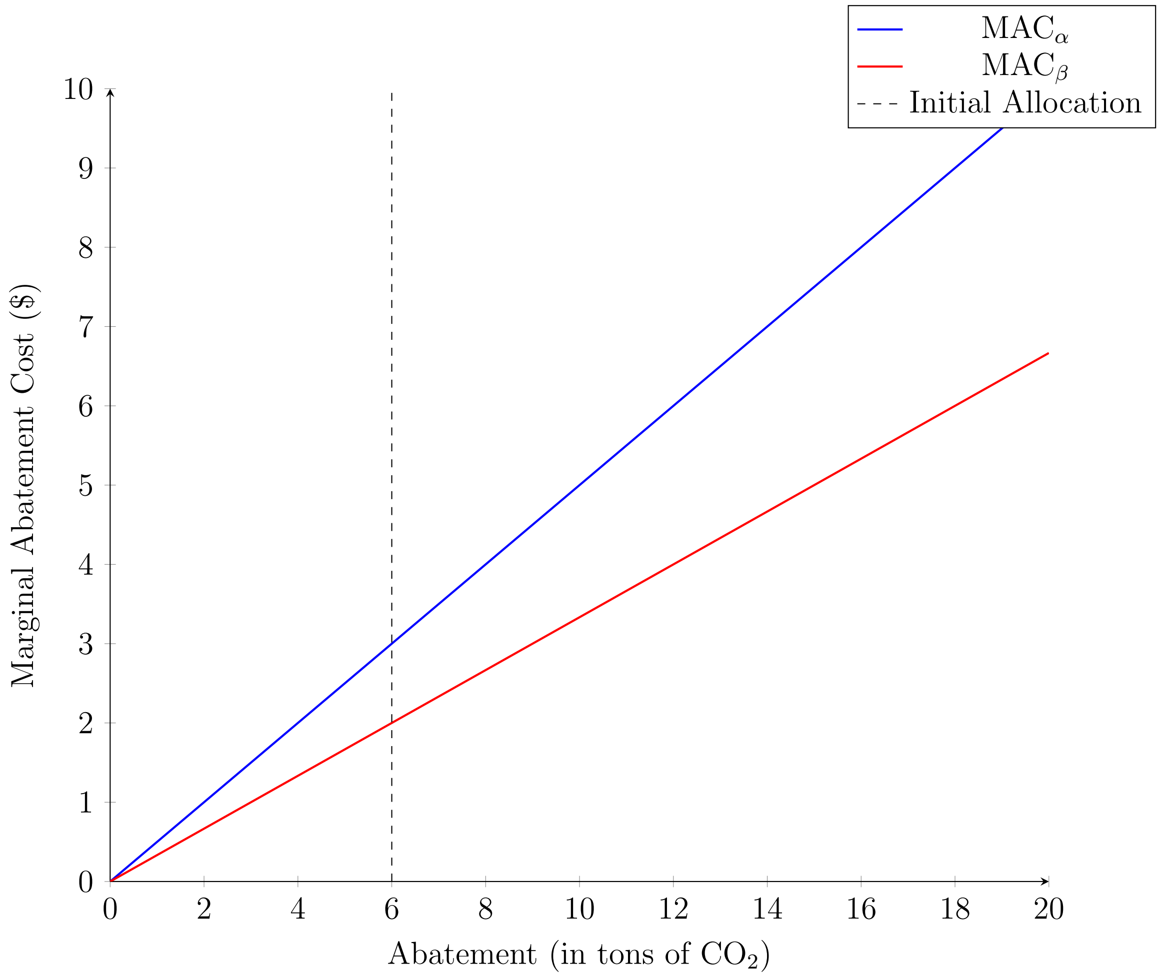
$$\text{TAC}_\beta = \int_0^6 \frac{A_\beta}{3}\, dA_\beta = \frac{1}{3}\int_0^6 A_\beta\, dA_\beta = \frac{1}{3}\left[\frac{A_\beta^2}{2}\right]_0^6 = \frac{1}{3}\left(\frac{6^2}{2}\right) = \$6$$




(c) $\text{TAC} = \text{TAC}_\alpha + \text{TAC}_\beta = 9 + 6 = \$15$

- Firm Alpha emits 18 tons of $CO_2$, with a total abatement cost of \$9
- Firm Beta emits 30 tons of $CO_2$, with a total abatement cost of \$6
- Total abatement cost for society: \$15

**4.3** (a) Each firm's marginal abatement cost curve and initial allocation of permits/emissions under this policy:




(b) The firms will trade permits until their marginal abatement costs are equal. Firm Alpha has a higher MAC than Firm Beta for the same level of abatement, creating an incentive for Alpha to buy permits and for Beta to sell permits.

(c) At equilibrium, the marginal abatement costs are equal: $\text{MAC}_\alpha = \text{MAC}_\beta$

$$\frac{A_\alpha}{2} = \frac{A_\beta}{3}.$$

$$A_\alpha = 2 \cdot A_\beta \quad \text{and} \quad A_\alpha + A_\beta = 12.$$

$$2 \cdot A_\beta + A_\beta = 12 \implies 3 \cdot A_\beta = 12 \implies A_\beta = 4.$$

$$A_\alpha = 2 \cdot 4 = 8.$$

$$\text{Price} = \frac{A_\beta}{3} = \frac{4}{3} \approx 1.33\,\$/\text{ton}$$

(d) The emissions after trading are:

- Firm Alpha: $18 - A_\alpha = 18 - 8 = 10\,\text{tons of } CO_2$
- Firm Beta: $30 - A_\beta = 30 - 4 = 26\,\text{tons of } CO_2$

(e) The total abatement cost for society is the sum of the abatement costs for both firms:

$$\text{TAC}_\alpha = \int_0^8 \frac{A_\alpha}{2}\,dA_\alpha = \frac{1}{2}\int_0^8 A_\alpha\,dA_\alpha = \frac{1}{2}\left[\frac{A_\alpha^2}{2}\right]_0^8 = \frac{1}{2}\left(\frac{8^2}{2}\right) = \$16$$

$$\text{TAC}_\beta = \int_0^4 \frac{A_\beta}{3}\,dA_\beta = \frac{1}{3}\int_0^4 A_\beta\,dA_\beta = \frac{1}{3}\left[\frac{A_\beta^2}{2}\right]_0^4 = \frac{1}{3}\left(\frac{4^2}{2}\right) = \frac{1}{3}\cdot 8 = \$2.67$$

$$\text{Total TAC} = \text{TAC}_\alpha + \text{TAC}_\beta = 16 + 2.67 = \$18.67$$

**4.4** (a) To achieve a total emissions reduction of 12 tons of $CO_2$, we can equate the marginal abatement costs of both firms under a uniform tax, since firms abate until MAC = Tax.

$$A_\alpha + A_\beta = 12$$

$$\text{MAC}_\alpha = \frac{A_\alpha}{2}, \quad \text{MAC}_\beta = \frac{A_\beta}{3}$$

$$\frac{A_\alpha}{2} = \frac{A_\beta}{3}$$

$$A_\alpha = \frac{2}{3}A_\beta$$

$$\frac{2}{3}A_\beta + A_\beta = 12$$

$$\frac{5}{3}A_\beta = 12 \implies A_\beta = \frac{12\cdot 3}{5} = 7.2\,\text{tons}$$

$$A_\alpha = 12 - A_\beta = 12 - 7.2 = 4.8\,\text{tons}$$

The tax per ton is:

$$\text{Tax} = \text{MAC}_\beta = \frac{A_\beta}{3} = \frac{7.2}{3} = 2.4\,\$/\text{ton}.$$

(b) The emissions for each firm are:

$$\text{Emissions}_\alpha = 24 - A_\alpha = 24 - 4.8 = 19.2\,\text{tons}$$

$$\text{Emissions}_\beta = 36 - A_\beta = 36 - 7.2 = 28.8\,\text{tons}$$

(c) The total tax payment for each firm is:

$$\text{Tax Payment}_\alpha = \text{Tax} \times \text{Emissions}_\alpha = 2.4 \times 19.2 = \$46.08$$

$$\text{Tax Payment}_\beta = \text{Tax} \times \text{Emissions}_\beta = 2.4 \times 28.8 = \$69.12$$

(d) The total abatement cost for each firm is the area under its MAC curve up to its abatement level:

$$\text{TAC}_\alpha = \int_0^{4.8} \frac{A_\alpha}{2}\,dA_\alpha = \frac{1}{2}\int_0^{4.8} A_\alpha\,dA_\alpha = \frac{1}{2}\left[\frac{A_\alpha^2}{2}\right]_0^{4.8} = \frac{1}{2}\left(\frac{4.8^2}{2}\right) = \$5.76$$

$$\text{TAC}_\beta = \int_0^{7.2} \frac{A_\beta}{3}\,dA_\beta = \frac{1}{3}\int_0^{7.2} A_\beta\,dA_\beta = \frac{1}{3}\left[\frac{A_\beta^2}{2}\right]_0^{7.2} = \frac{1}{3}\left(\frac{7.2^2}{2}\right) = \$8.64$$

$$\text{Total TAC} = \text{TAC}_\alpha + \text{TAC}_\beta = 5.76 + 8.64 = \$14.40$$

**4.5** To minimize total societal abatement costs, a government regulator would compare the command-and-control policy, tradeable pollution permits, and tax policy. Under the command-and-control policy, where each firm abates 6 tons of CO, the total cost is \$15, with Firm Alpha's cost at \$9 and Firm Beta's at \$6. The tradeable pollution permits policy, allowing firms to trade permits until marginal abatement costs equalize, results in a higher total cost of \$18.67, with Firm Alpha's cost at \$16 and Firm Beta's at \$2.67. The tax policy, where firms abate until marginal abatement costs equal the tax, achieves the lowest total cost of \$14.4, with Firm Alpha's cost at \$5.76 and Firm Beta's at \$8.64. The tax policy is preferred because it minimizes costs by aligning abatement levels with marginal abatement costs, ensuring flexibility for firms to abate based on their cost structures, and provides ongoing market-driven incentives for innovation.

Therefore, the tax policy achieves the desired emissions reduction at the lowest cost to society while promoting efficiency and economic adaptability.