Topic 6

- Analysis of abatement decisions
- Equimarginality

Environmental Regulation

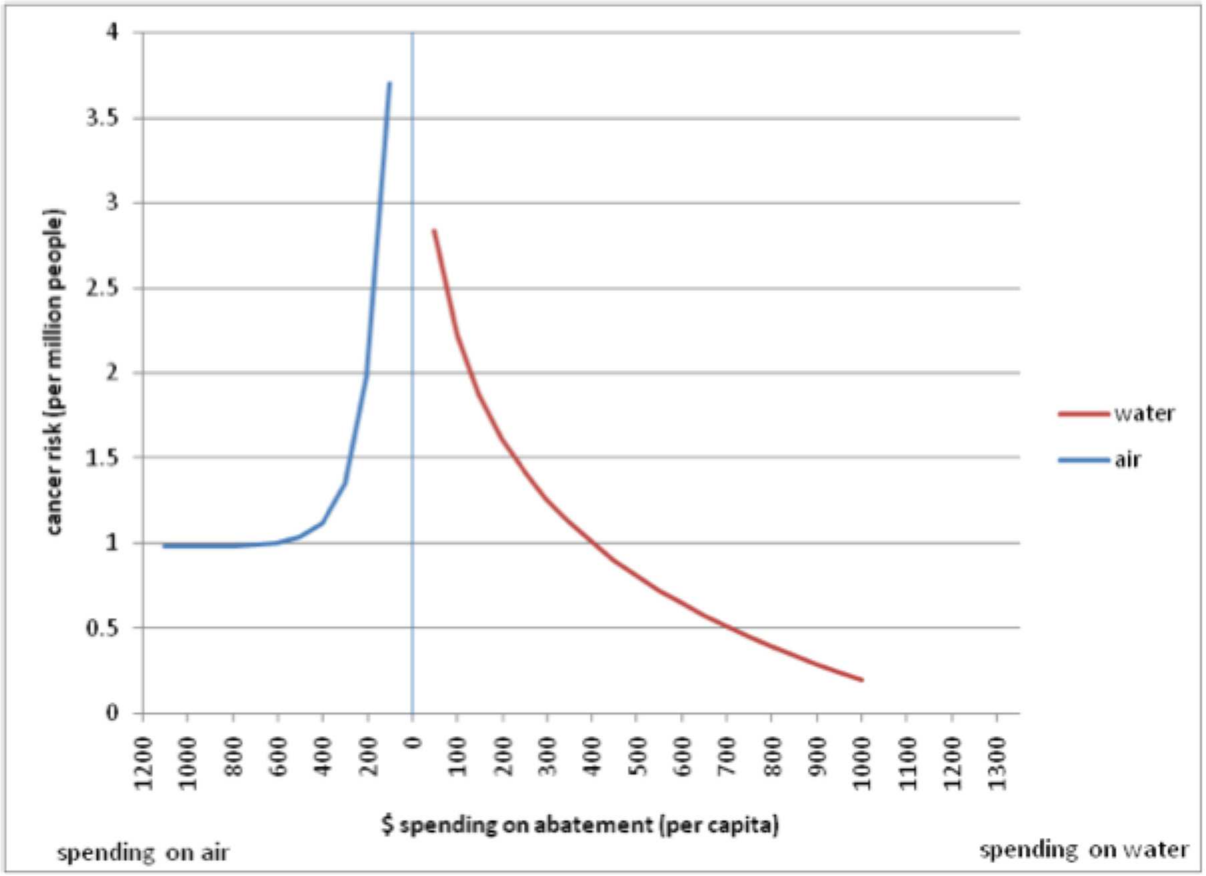
- Which do you prefer?

- Spend \$1,000 per capita on regulation such that:
  - ▷ average cancer risk is 1 in 1 million from lifetime exposure to air pollution and 1 in 1 million for lifetime exposure to water pollution or
  - ▷ average cancer risk is 1.2 in 1 million from lifetime exposure to air pollution and 0.7 in 1 million for lifetime exposure to water pollution

Key Lesson

- Both policies cost the same
  - ▷ The first leads to $300 + 300 = 600$ deaths
  - ▷ The second leads to $360 + 210 = 570$ deaths
- Get the most out of your money
- Generally do not want to equalize the averages
- Generally do want to equalize the *marginals*

Equalize the Marginals



Equalizing the Marginals

- Blackboard presentation

Math for Equalizing the Marginals

- The problem is

$$\max[b_w(a_w) + b_a(a_a)] \text{ subject to } a_w + a_a = a$$

- The first order conditions for this problem are

$$\frac{d\,b_w(a_w)}{d\,a_w} = \frac{d\,b_a(a_a)}{d\,a_a}$$

$$a_w + a_a = a$$

- In words, equate the marginals. Evaluate the horizontal sum of the marginals at $a_w + a_a$ to get marginal abatement cost.

Equalizing the Marginals Analytically – 1

- Use the values read from the graph for the blackboard presentation

- Fit the benefit function

$$\text{Benefit} = 4 - \text{Cancer Risk} = \exp(\alpha + \beta \times \text{Abatement})$$

  statistically for both water and air

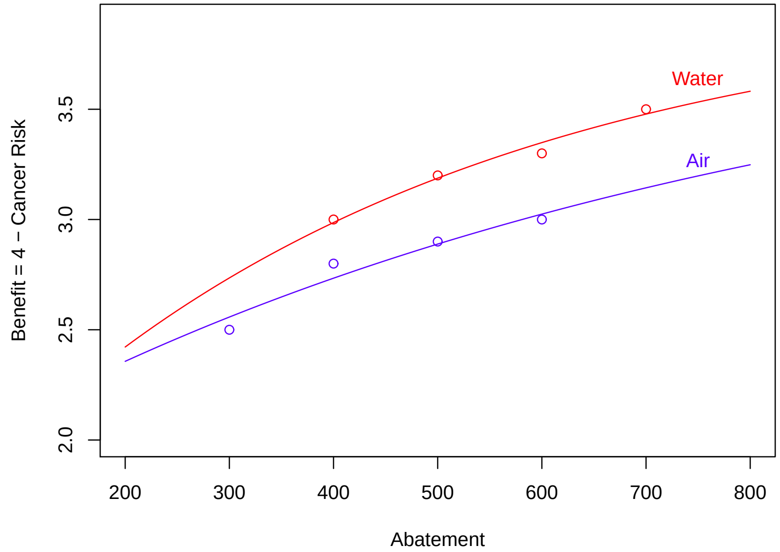
  ▷ "Benefit" is computed as a benchmark minus cancer risk because cancer risk is a "bad"

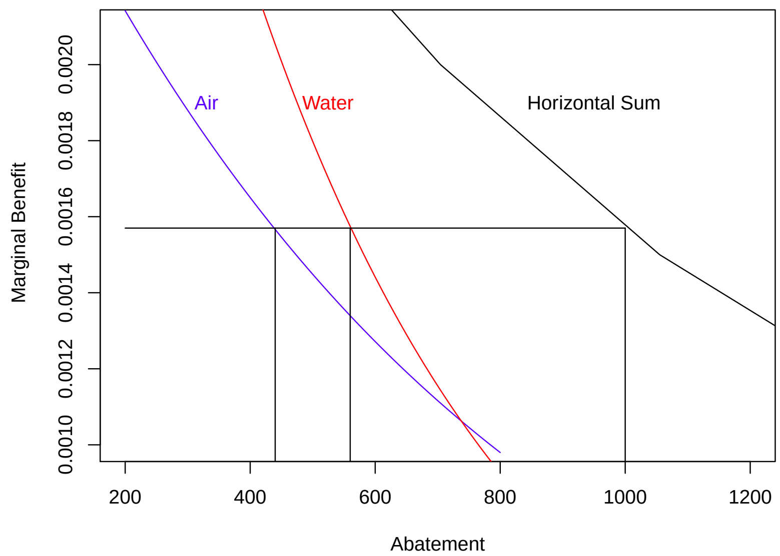
- Differentiate to get marginal benefit curves for water and air.

- Equate the marginals and evaluate the horizontal sum at \$1000 – **next slide**.

- Result, **next slide**, \$440 for water and \$560 for air.

Equalizing the Marginals Analytically – 2





Cost-Benefit Analysis

- E – actual emissions
- E^B – baseline emissions without abatement
- A – abatement (reduction in emissions): $A = E^B - E$
- $B(A)$ – benefits of abatement (benefits of reduced pollution)
- $C(A)$ – costs of abatement (note: sometimes C means production cost)
- Want to maximize net benefits

$$\max_A B(A) - C(A)$$

Typical Assumptions

- Convex $C(A)$ and concave $B(A)$
- Interpretations
  - ▷ Increasing marginal abatement cost
  - ▷ Diminishing marginal utility of a clean environment

Increasing Marginal Abatement Cost

Product	Incremental Abatement	Cost	Marginal Cost
Katadyn Micro Filter Water Bottle	EPA standards for removal of Giardia and bacteria	$39.95	
Katadyn Hiker Filter	Also particles down to .3 microns	$59.95	$20.00
Sawyer Water Treatment System	Also particles down to .1 microns	$89.00	$29.05

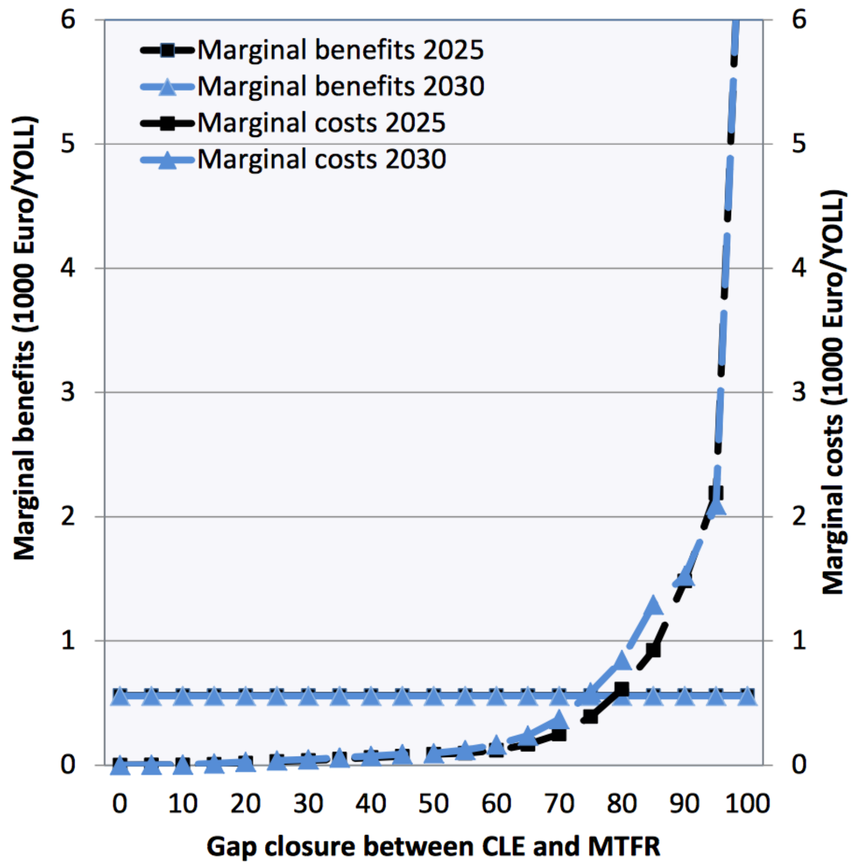
Source: REI.com

Decreasing Marginal Benefits of Abatement?

Ozone Concentration (ppm) (8-hour average, unless noted)	Air Quality Index Values	Air Quality Descriptor
0.0 to 0.064	0 to 50	Good
0.065 to 0.084	51 to 100	Moderate
0.085 to 0.104	101 to 150	Unhealthy for Sensitive Groups
0.105 to 0.124	151 to 200	Unhealthy
0.125 (8-hr.) to 0.404 (1-hr.)	201 to 300	Very Unhealthy

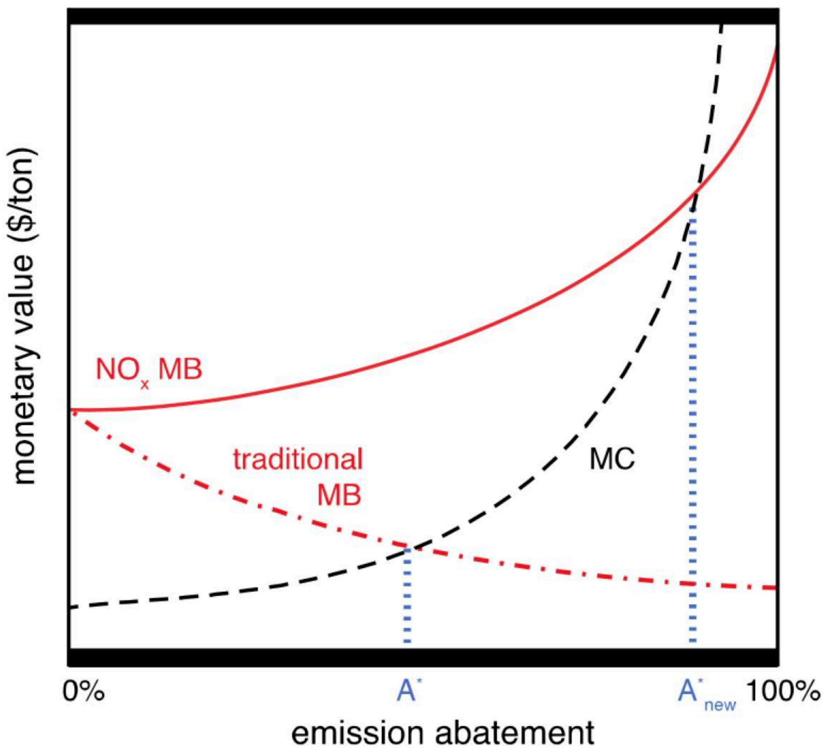
- Premature death, asthma, bronchitis, heart attack, lung damage
- Below 40 ppb – few health effects
- EPA ozone standard is 75 ppb

Marginal Costs and Benefits of Abatement – 1



- Particulate and ozone health, crop, etc. damages
- CLE 2013 legislation, MTFR maximum technically feasible
- Source: http://www.iiasa.ac.at/web/home/research/researchPrograms/MitigationofAirPollutionandGreenhousegases/9._Holland_Costs_and_benefits.pdf

Marginal Costs and Benefits of Abatement–2



- Source: Amanda Joy Pappin, S. Morteza Mesbah, Amir Hakami, and Stephan Schott (2015), "Diminishing Returns or Compounding Benefits of Air Pollution Control? The Case of NOx and Ozone," *Environmental Science and Technology*

Simple Analytics of Cost-Benefit Analysis

- $\max_A B(A) - C(A)$
- $B'(A) - C'(A) = 0$
- marginal benefit of abatement = marginal cost of abatement
- lingo: marginal willingness to pay = marginal abatement cost
  - ▷ MWTP = MAC
- *Good* government tries to create incentives for firms to choose this level of pollution reduction

Good Government Tries to Create Incentives for Firms to Choose the Optimum Quantity of Polution Reduction

- We shall next investigate how firms respond to various gov-erment incentives.
  - ▷ Policies that affect price: taxes and subsidies.
  - ▷ Policies that affect quantity: cap and trade.

Responses to Regulation

- 2 firms supplying a competitive world market with $P = 60$
- $C_1(Q_1) = 300 + 2Q_1^2$ and $C_2(Q_2) = 500 + Q_2^2$
  - ▷ fixed cost not sunk
- $MC_1(Q_1) = 4Q_1$ and $MC_2(Q_2) = 2Q_2$
  - ▷ 2 has higher fixed cost, lower marginal cost
- Produce emissions $E_1 = Q_1$ and $E_2 = Q_2$
  - ▷ emissions closely tied to output
- Marginal damage from a unit of pollution $MD = 12$

Questions

- What will firms produce?
- What is the efficient outcome?
- What if the government imposes a tax of $12 per unit of emission?
- What if the government offers a subsidy of $12 per unit of pollution abatement?
- What if the government issues 36 tradeable emission permits using a clock auction?
- What if the government distributes 18 permits to each firm at no charge?

Answers

	Market Outcome	Efficient Outcome	Tax = $12	Subsidy = $12	36 Permits by Auction	18 Permits Each Free
Q_1						
Q_2						
Profit 1						
Profit 2						
$E_1 + E_2$						
Damage						

Blackboard presentation.

A Firm's Abatement Decisions

- In the forgoing analysis of a firm's response to regulation we have considered the relationship of environmental damage to output as fixed.
  - ▷ In a tax or subsidy setting, the only tool the firm had available to control environmental damage was to vary output.

A Firm's Abatement Decisions

- We will now consider the case where the firm can change the relationship of output to environmental damage by employing abatement technologies.

  ▷ The firm must now choose two variables to maximize profits:

  1. How much output Q to produce.

  2. How much abatement A to engage in to reduce environmental damage.

  ▷ This is similar mathematically to the two variable problem of choosing output Q and the number of permits X to trade under a cap and trade regime.

Abatement Decision, Quantity Known

- To begin, we will first consider simple tabular example of how to choose abatement when the output is known.

- Under tax and subsidy regimes.

- Next slide.

Emissions Taxes vs. Abatement Subsidies

Emissions (tons/month)	Abatement (tons/month)	Total Abatement Cost	Marginal Abatement Cost	Total Tax at \$120/ton	Total Tax Plus Total Abatement Cost
10	0	0	15	1200	1200
9	1	15	30	1080	1095
8	2	45	50	960	1005
7	3	95	70	840	935
6	4	165	95	720	885
5	5	260	115	600	860
4	6	375	150	480	855
3	7	525	185	360	885
2	8	710	230	240	950
1	9	940	290	120	1060
0	10	1230		0	1230

- Emission tax \$120/ton, output held fixed

Emissions Taxes vs. Abatement Subsidies

Emissions (tons/month)	Abatement (tons/month)	Total Abatement Cost	Marginal Abatement Cost	Total Subsidy at $120/ton	Total Subsidy Minus Total Abatement Cost
10	0	0	15	0	0
9	1	15	30	120	105
8	2	45	50	240	195
7	3	95	70	360	265
6	4	165	95	480	315
5	5	260	115	600	340
4	6	375	150	720	345
3	7	525	185	840	315
2	8	710	230	960	250
1	9	940	290	1080	140
0	10	1230		1200	-30

- Abatement subsidy $120/ton, output held fixed

Conclusion

- At any level of output, either a per unit tax or a per unit subsidy on emmissions will cause the firm to choose the same amount of abatement.
  - ▷ Unless the tax puts the firm out of business.

Taxes vs. Subsidies

- The next slide considers the case where both quantity and abatement can be chosen by the firm.

Analytics of Taxes vs. Subsidies

- With a tax of $\$120$/ton

$$\max_{Q,A} P(Q)\cdot Q - C(Q) - (E(Q) - A)\cdot 120 - \text{Abatement Cost}(A)$$

- With a subsidy of $\$120$/ton

$$\max_{Q,A} P(Q)\cdot Q - C(Q) + (\text{Base} - E(Q) + A)\cdot 120 - \text{Abatement Cost}(A)$$

Marginal Equations for Taxes vs. Subsidies

- With a tax of $\$120$/ton

$$\begin{aligned} MR(Q) - MC(Q) - 120ME(Q) &= 0 \\ 120 - MAC(A) &= 0 \end{aligned}$$

- With a subsidy of $\$120$/ton

$$\begin{aligned} MR(Q) - MC(Q) - 120ME(Q) &= 0 \\ 120 - MAC(A) &= 0 \end{aligned}$$

- Tax is equivalent to a subsidy when output Q and abatement A can both be varied.
  - ▷ As long as entry decisions are not affected.

Efficiency: Which Policy to Choose?

- Most taxes on labor, capital, etc. are distortionary.
  - ▷ They reduce economic efficiency.
- Taxes on environmental damage improve economic efficiency.
  - ▷ Thus, distortionary taxes can be replaced by efficiency improving environmental damage taxes.
- From this point of view, taxes are better than subsidies.
- Similarly, selling permits is better than giving them away.

Innovation: Which Policy to Choose?

- Command and control policies kill innovation.

- All market based policies are better than command and control policies.

Monitoring: Which Policy to Choose?

- Market based policies require monitoring.
  - ▷ The costs of monitoring can be large enough that a market based policy is not practicable.

- Command and control policies may be the only option.
  - ▷ Catalytic converters.
  - ▷ Double-hulled tankers.

Uncertainty: Which Policy to Choose?

- Taxes and subsidies are picking something on the price axis.
  - ▷ Risky if marginal benefit curve is steep and marginal abatement cost curve is flat.

- Permits are picking something on the quantity axis.
  - ▷ Risky if marginal benefit curve is flat and marginal abatement cost curve is steep.

- Illustrate with next two slides from Keohan and Olmstead.

Uncertainty: Which Policy to Choose?

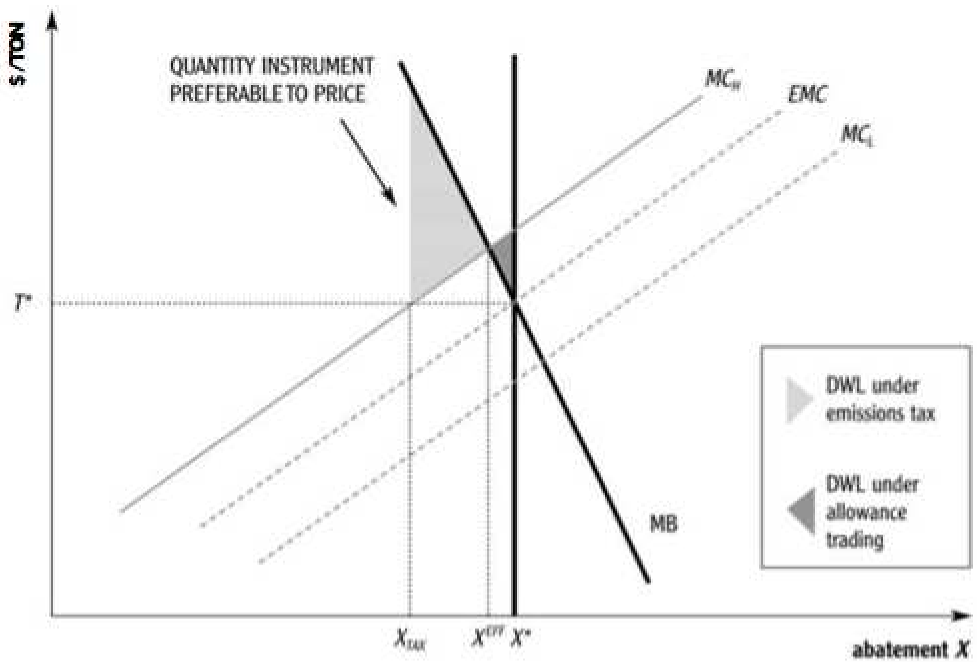


Figure 8.3 Comparison of price (emissions tax) and quantity (allowance trading) instruments under marginal cost uncertainty. The solid marginal cost line, denoted MC_H, represents the actual high marginal abatement cost curve, which is unknown to the regulator in advance. The bottom dashed line parallel to it, denoted MC_L, shows the alternative possibility (equally likely ahead of time) of a low marginal abatement cost curve. The middle line (*EMC*) is the expected marginal cost curve. The figure depicts a case in which marginal benefit is steeper than marginal cost, hence the cap-and-trade policy is preferable (smaller deadweight loss).

Uncertainty: Which Policy to Choose?

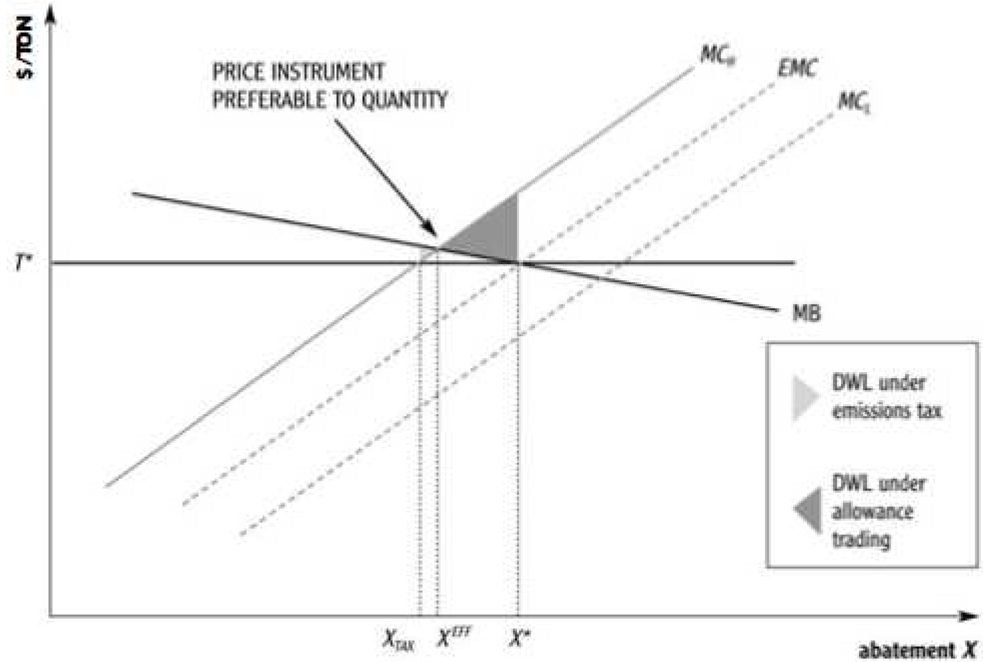


Figure 8.4 Comparison of price (emissions tax) and quantity (allowance trading) instruments under marginal cost uncertainty. In this case, marginal benefit is flat relative to marginal cost, and the emissions tax (the price instrument) is preferred. All else is as in figure 8.3.

Aracruz Celulose

- Aracruz Celulose, S.A. (Brazil)
  - ▷ World's leading producer of bleached eucalyptus pulp
  - ▷ Market value (2007) US $7.7 billion
- Guaíba Unit
  - ▷ Capacity of 450,000 tons of eucalyptus pulp per year

Aracruz Celulose Waste Streams

Guaíba Unit -- Solid Wastes Generated	
Type of waste	**Quantity generated (t)**
Organic mud	82,174.24
Dregs and grits	36,799.21
Lime mud	8,658.20
Eucalyptus bark	15,183.40
Sawdust	33,664.49
Heavy ashes	9,969.06
Light ashes	53,045.84
Garbage	1,712.04
Digestor discards	2,525.87
Scrap metal	431.36
Scrap paper	162.5
Plastic and glass	79.32
Wood scrap	122.33
TOTAL	**244,527.71**

- Aracruz has a good understanding of its waste streams

Aracruz Abatement

Abatement at Aracruz Celulose, S.A.

Alternative	Pollution (AOX, in kg per year)	Incremental abatement (kg per year)	Total annual cost	Increase in total annual cost	Marginal cost (per kg of additional abatement)
1. Standard pulp (baseline)	1,000,000	No reduction	$0	$0	$0
2. ECF pulp using chlorine dioxide	250,000	750,000	$28.5 million	$28.5 million	$3.80
3. ECF + oxygen delignification	200,000	50,000	$29.6 million	$1.1 million	$22
4. TCF pulp using ozone	10,000	190,000	$40.4 million	$10.6 million	$56

Source: Keohane and Olmstead (2007, p.26)
AOX = Adsorbable Organic Halides, e.g., dioxin
Based on 250,000 tons of pulp/year
Combined variable and capital costs using 10% interest rate

- Consider expansion of Guaíba Unit and the possibility of marketing pulp to environmentally conscious customers in Europe

Thinking In Terms of Marginals

Abatement at Aracruz Celulose, S.A.

Alternative	Pollution (AOX, in kg per year)	Incremental abatement (kg per year)	Total annual cost	Increase in total annual cost	Marginal cost (per kg of additional abatement)	Early 1990s marginal benefit*	Current marginal benefit*
1. Standard pulp (baseline)	1,000,000	No reduction	$0	$0	$0		
2. ECF pulp using chlorine dioxide	250,000	750,000	$28.5 million	$28.5 million	$3.80	$1.00	$4.00
3. ECF + oxygen delignification	200,000	50,000	$29.6 million	$1.1 million	$22	$1.10	$4.50
4. TCF pulp using ozone	10,000	190,000	$40.4 million	$10.6 million	$56	$2.00	$5.00

Source: Keohane and Omstead (2007, p.26)

AOX = Adsorbable Organic Halides, e.g., dioxin

Based on 250,000 tons of pulp/year

Combined variable and capital costs using 10% interest rate

*Estimates for illustration

Equimarginality

- Equimarginal Rule: The efficient level of abatement occurs where marginal benefit equals marginal cost.

- Given a fixed level of expenditure on environmental initiatives, firms should allocate resources so as to equalize the marginal benefits associated with those initiatives