Lecture 06

Tradable Permits

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AEM 4510

Roadmap

1. How do tradable permit systems work in theory and in the real world?
2. What happens under a tradable permit system?

Tradable permits

Tradable permits

How do tradable permit systems work?[1]

[1] Tradable permit systems are also called cap and trade systems.

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This is easy with one firm, but what if we have several, or hundreds?

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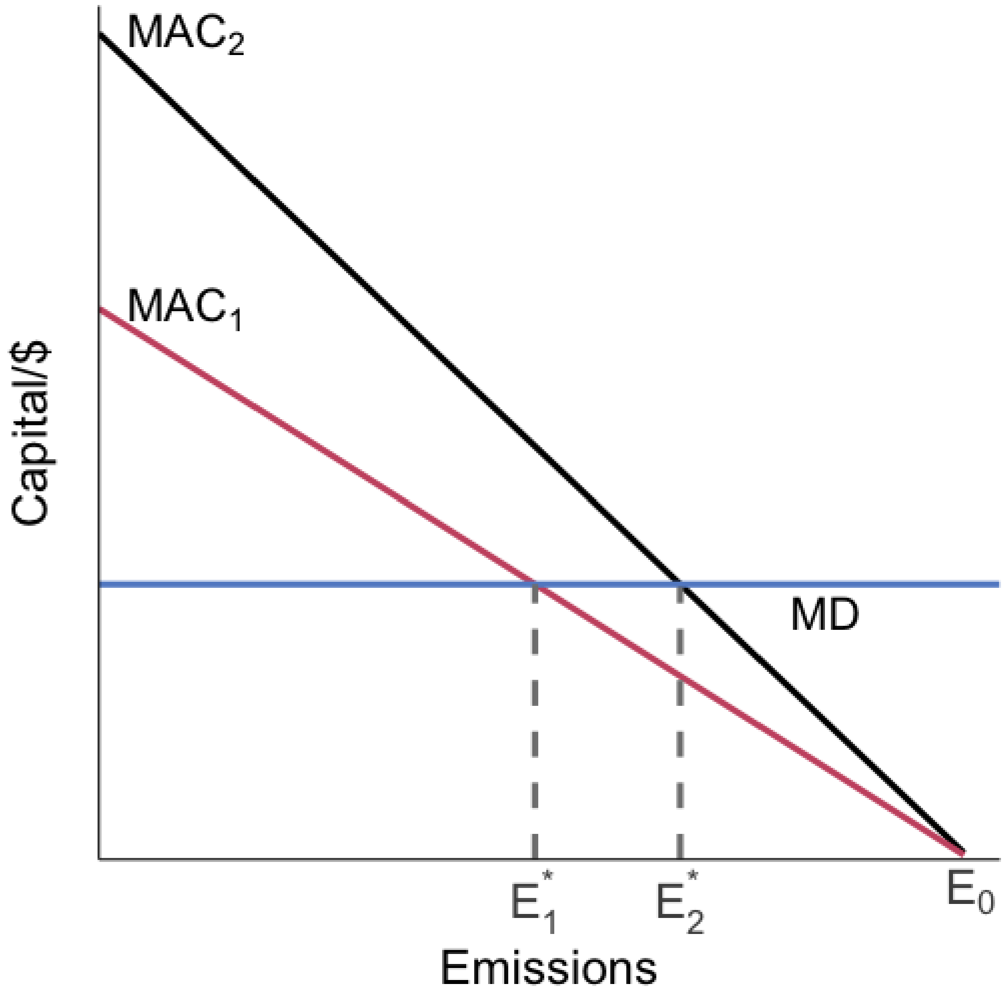
Optimal policy with multiple firms



Firm #2 is 'dirty': has higher MAC

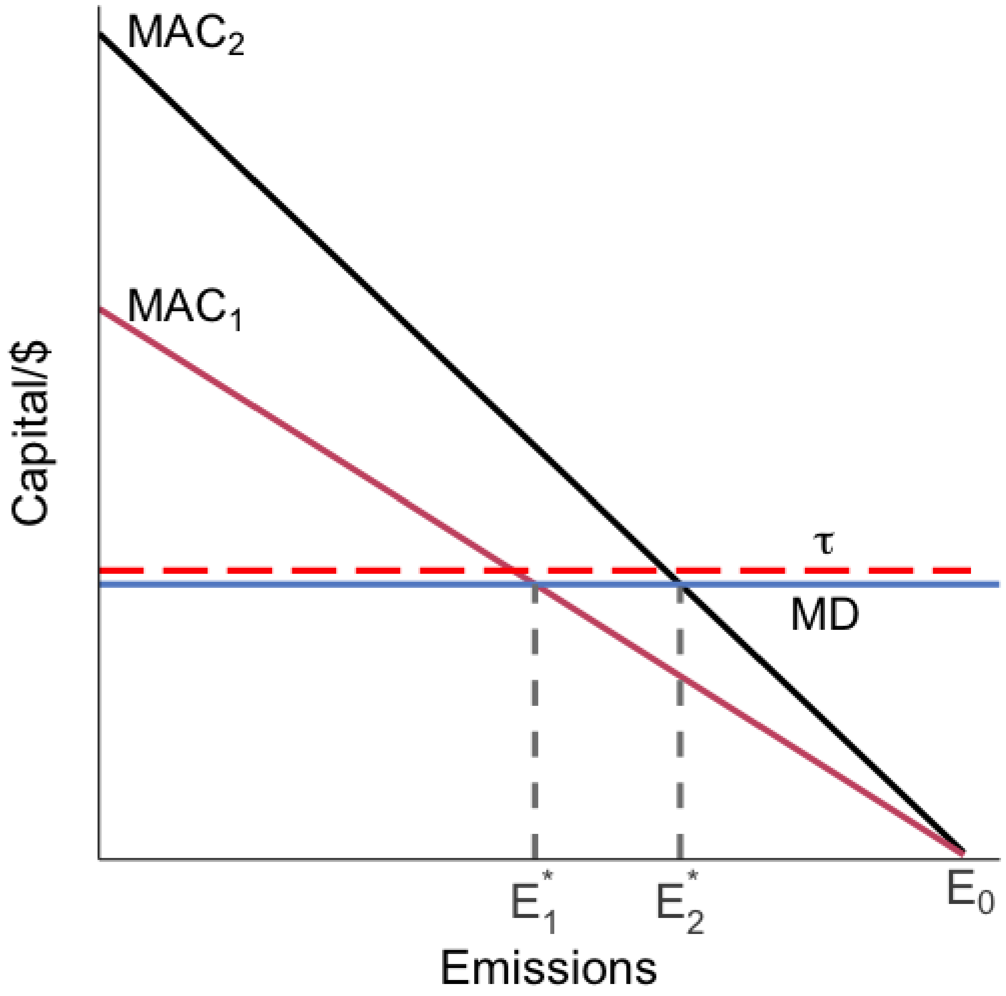
Firm #1 is 'clean': has lower MAC

If we use a regular emission standard: it has to be firm-specific!

Mandate E_1^* for 1 and E_2^* for 2

This requires **a lot** of info and political capital on behalf of the regulator

Optimal policy with multiple firms



Regulating multiple heterogeneous firms with a tax can be easy:

If MD is constant, then since firms select MAC = τ, as long as we set $\tau = MD$, we can achieve the efficient outcome (MAC = MD) without knowing anything about the firms!

Optimal policy with multiple firms

Taxes also achieve the **cost-effective** outcome: achieving a given emission level at least-cost

Let's see why

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The plants have abatement cost functions: $C_1(E_1)$ and $C_2(E_2)$

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Write down the regulator's problem

Optimal policy with multiple firms

$$\min_{E_1, E_2} C_1(E_1) + C_2(E_2) \quad \text{subject to: } E_1 + E_2 = \bar{E}$$

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Solve the constraint for $E_2 = \bar{E} - E_1$ so we have a simpler problem:

$$\min_{E_1} C_1(E_1) + C_2(\bar{E} - E_1)$$

Optimal policy with multiple firms

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$$\min_{E_1} C_1(E_1) + C_2(\bar{E} - E_1)$$

Take the first-order condition to find what is necessary for a cost minimum:

$$C_1'(E_1) + C_2'(\bar{E} - E_1) \times (-1) = 0$$

Optimal policy with multiple firms

This gives us:

$$\underbrace{-C_1'(E_1)}_{\text{MAC}_1} = \underbrace{-C_2'(\overbrace{\bar{E} - E_1}^{E_2})}_{\text{MAC}_2}$$

The marginal abatement costs across the sources must be equal at the cost-effective pollution level

Optimal policy with multiple firms

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This is called the **equimarginal principle**

Optimal policy with multiple firms

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Why?

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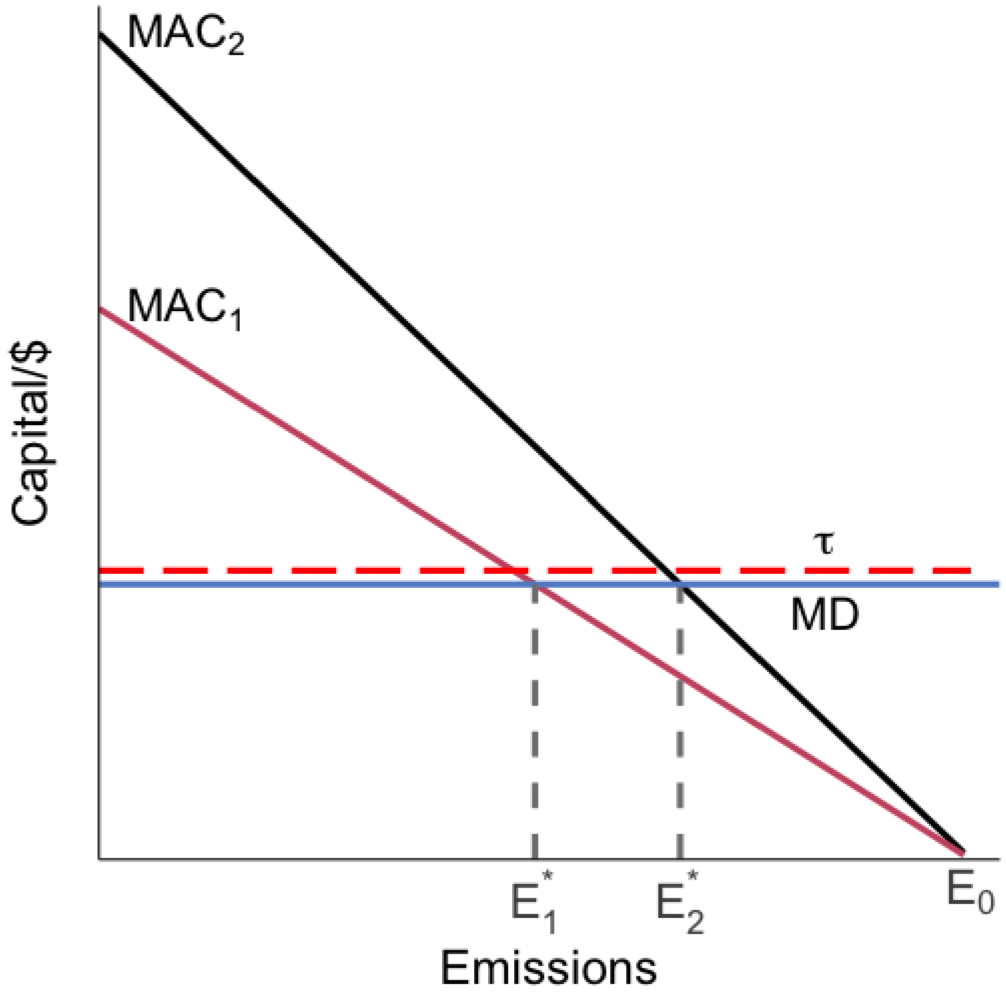
This means all firms' MACs are equal!

Even if we don't set the tax equal to MD, whatever emission reduction we get will be as cheap as possible

Optimal policy with multiple firms



The big problem is political feasibility

Firms resist taxation because they have to pay a fine for each unit of emissions

Tradable permit systems are a way to make emission standards flexible enough to handle heterogeneous firms

Tradable permit systems

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If firm 1 sells an allowance/permit to firm 2, their new restrictions are: $\bar{E}_1 - 1$ and $\bar{E}_2 + 1$

Tradable permit systems: example

The US Acid Rain Program is the classic example

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Permit = license to create 1 ton of SO_2

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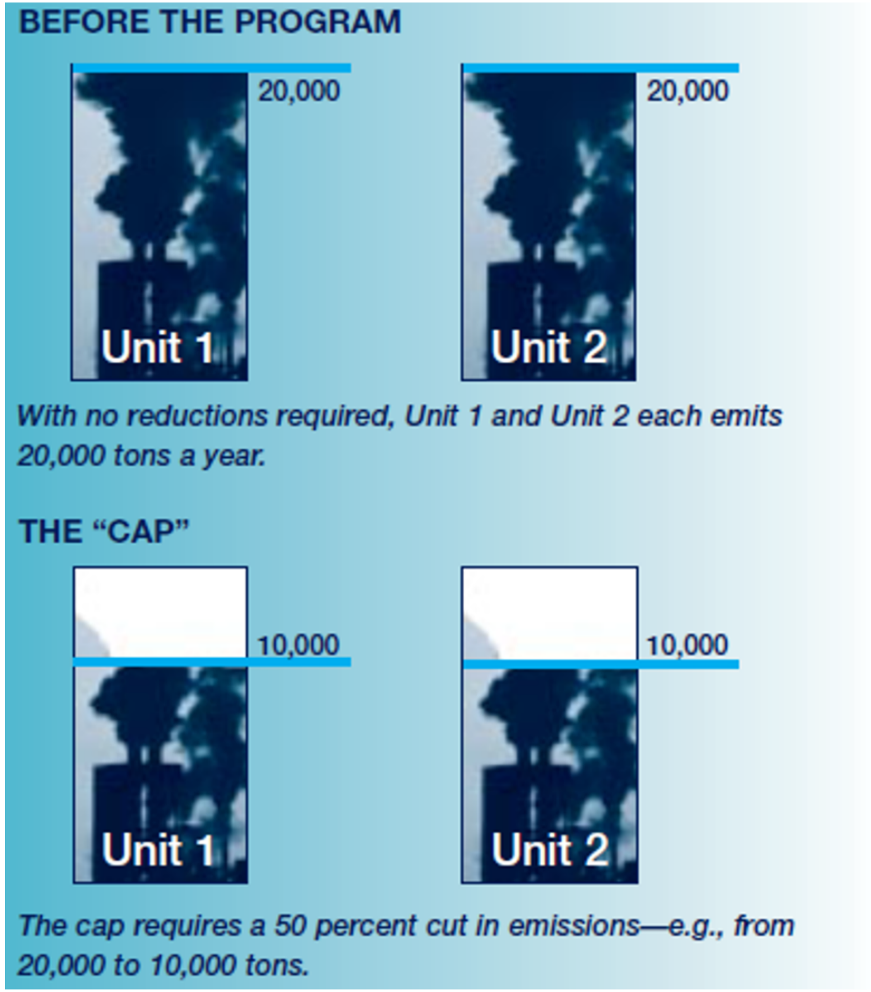
Phase I (1995-2000):

- 6.3 million permits issued per year
- affected 263 generating units at 110 dirtiest power plants

Phase II (2000+):

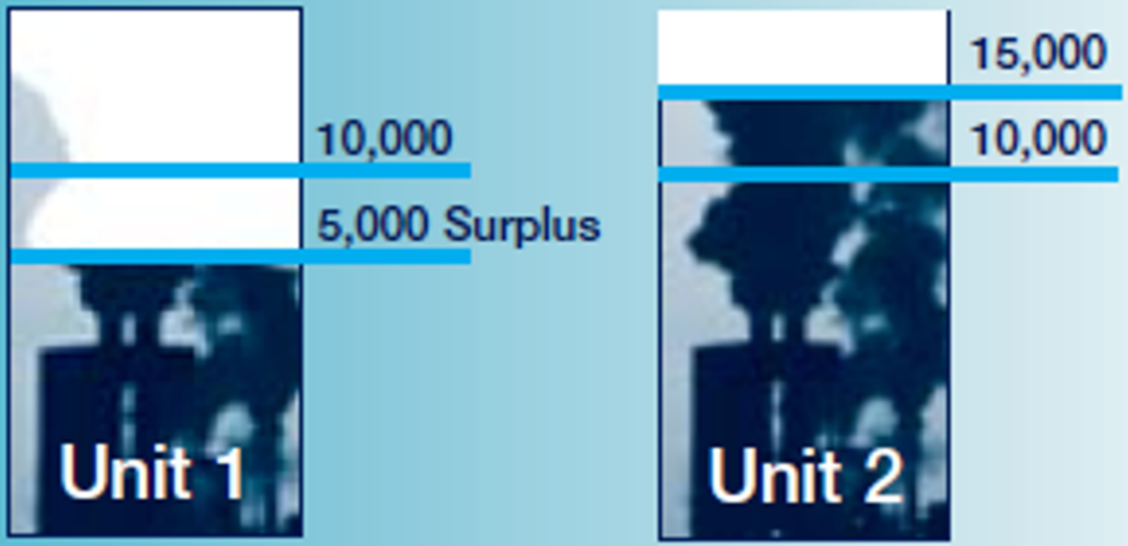
- 9 million permits issued per year
- affects all power plants over some minimum size

Tradable permit systems: example



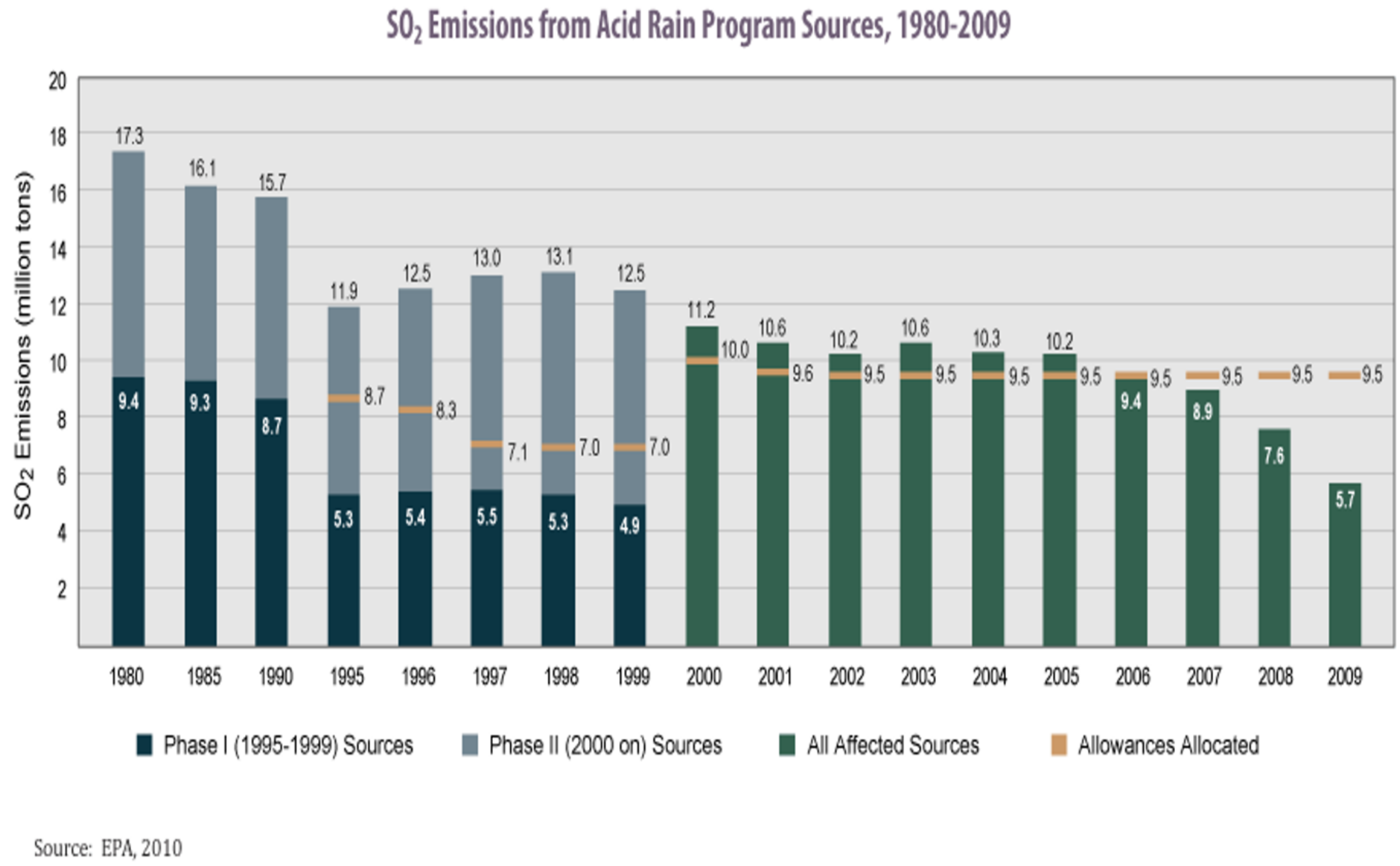
Tradable permit systems: example

EMISSIONS TRADING UNDER THE CAP



If Unit 1 can efficiently reduce 15,000 tons of emissions and Unit 2 can only efficiently reduce 5,000 tons, trading allows each unit to act optimally while ensuring achievement of the overall environmental goal. Unit 1 can hold on to (and "bank") its excess allowances or can sell them to Unit 2, whereas Unit 2 must acquire allowances from Unit 1 or from another source in the program.

Tradable permit systems: example



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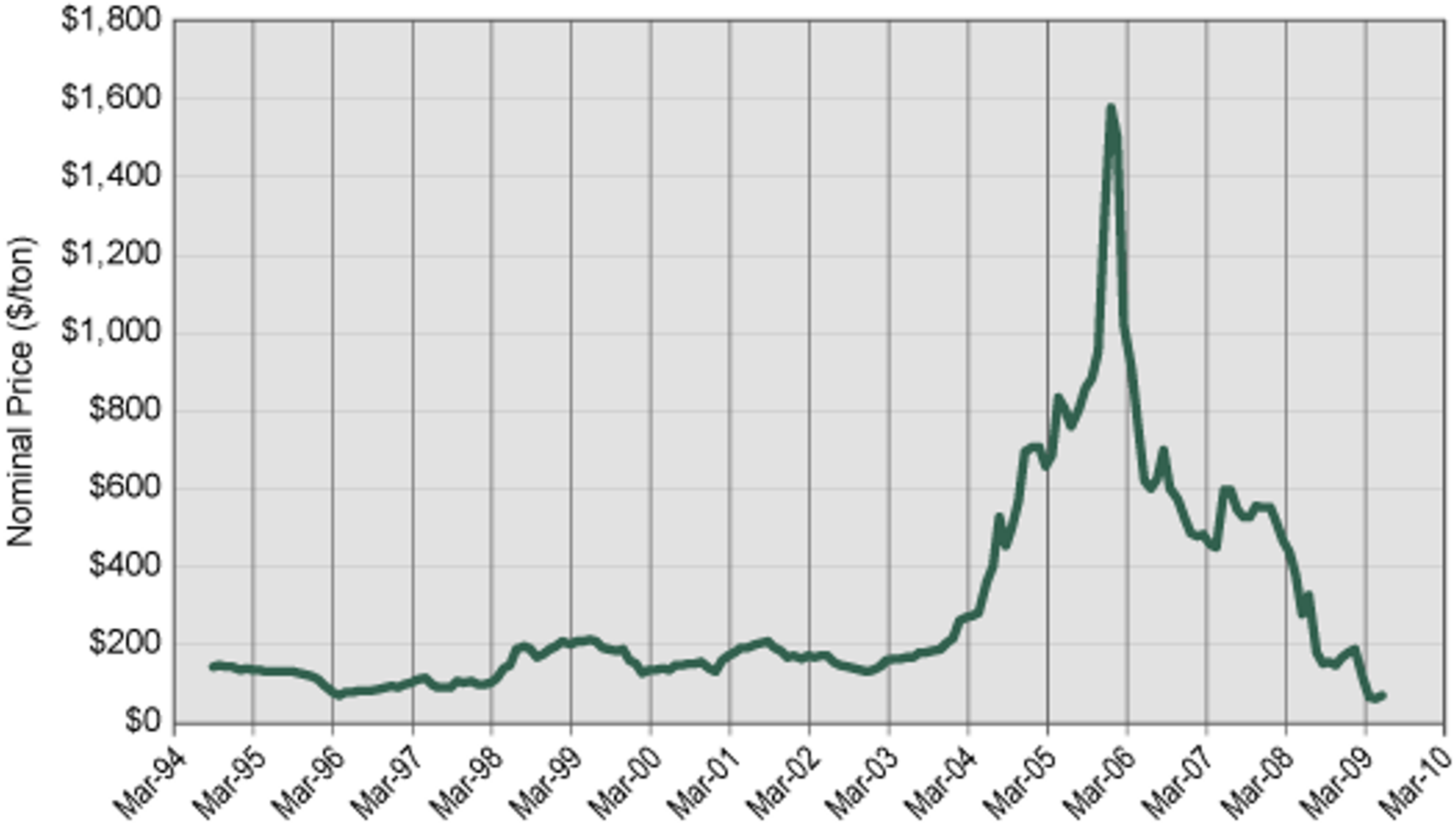
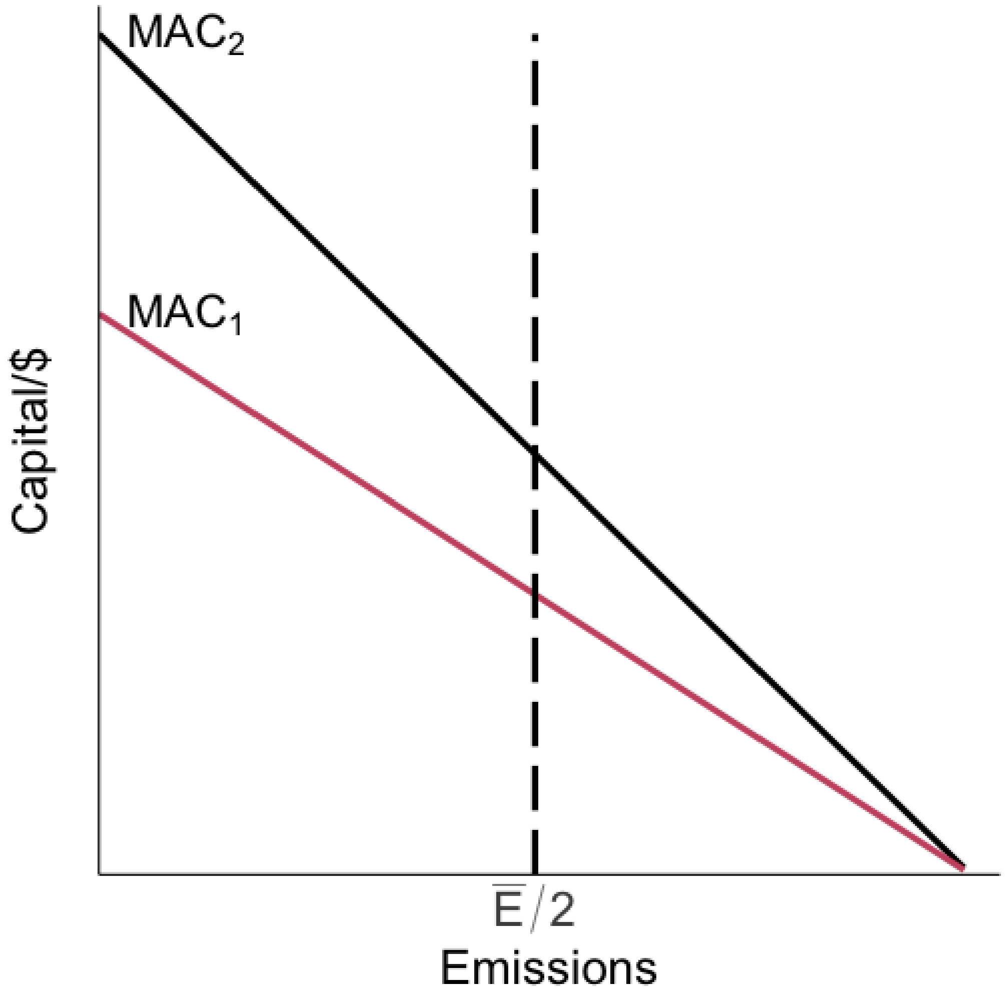


Tradable permit systems: example

Quantified benefits*:		
$PM_{2.5}$ mortality (U.S. and southern Canada)	$107,000	
$PM_{2.5}$ morbidity (U.S. and southern Canada)	$8,000	
Ozone mortality (eastern U.S.)	$4,000	
Ozone morbidity (eastern U.S.)	$300	
Visibility at parks (3 U.S. regions)	$2,000	
Recreational fishing in NY	$65	
Ecosystem improvements in Adirondacks (NY residents)	$500	
Total annual quantified benefits		$122,000
Quantified costs for U.S. power generation:		
SO_2 controls	$2,000	
NO_X controls	$1,000	
Total annual quantified costs		$3,000

Tradable permits: graphical



Suppose we want to limit to $\bar{E}$ total emissions so each firm gets $\bar{E}/2$ permits, but cant trade them

This can't be efficient (i.e. maximize social welfare given some MD curve)

It also can't be cost-effective: it doesn't minimize the cost of achieving $\bar{E}$ total emissions

Tradable permits: cost-effectiveness

For cost-effectiveness, we need total costs to be minimized for achieving a given level of emissions:

$$\min_{E_1,E_2} C_1(E_1) + C_2(E_2) \;\text{ subject to: } E_1 + E_2 = \bar{E}$$

This is the same problem as:

$$\min_{E_1,E_2} C_1(E_1) + C_2(\bar{E} - E_1)$$

which has a solution where:

$$-C_1'(E_1^*) = -C_2'(\bar{E} - E_1^*)$$

Tradable permits: cost-effectiveness

Cost-effectiveness requires:

$$-C_1'(E_1^*) = -C_2'(\bar{E} - E_1^*) \leftrightarrow MAC_1 = MAC_2$$

That marginal abatement costs are equal across all emitters

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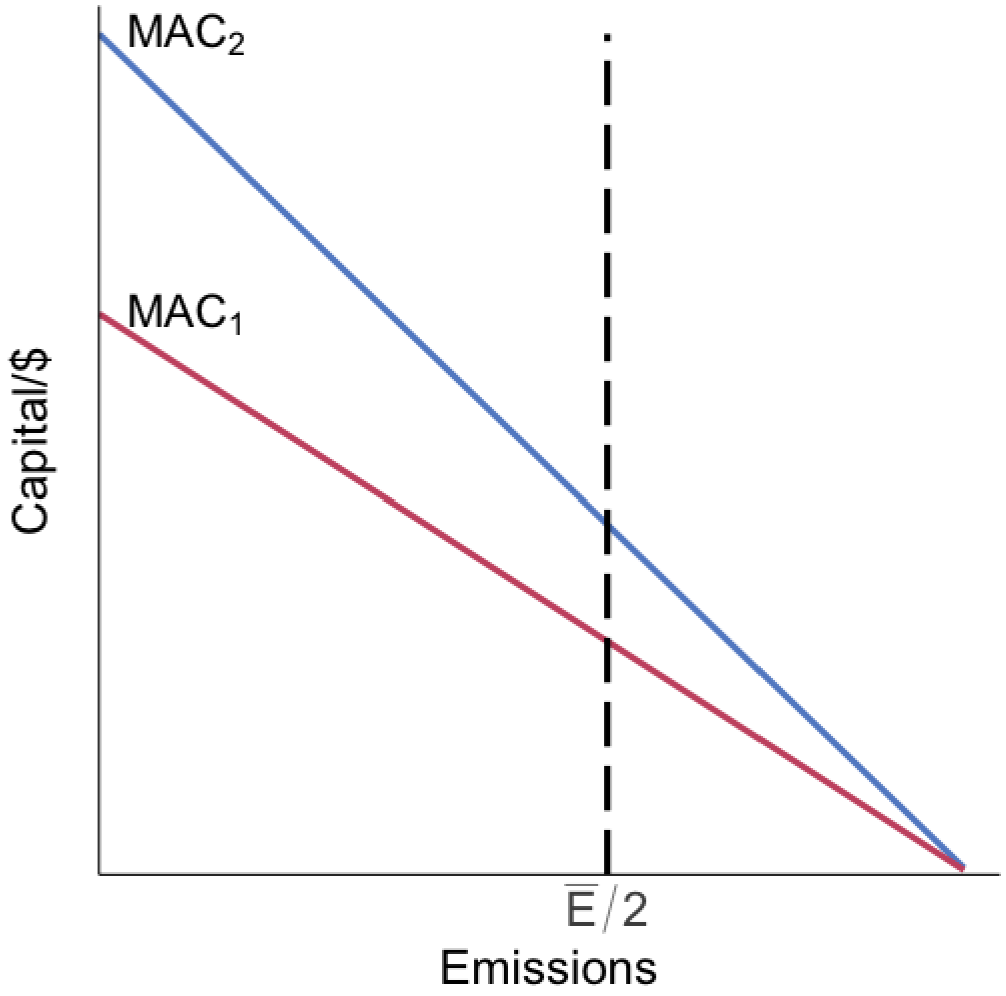
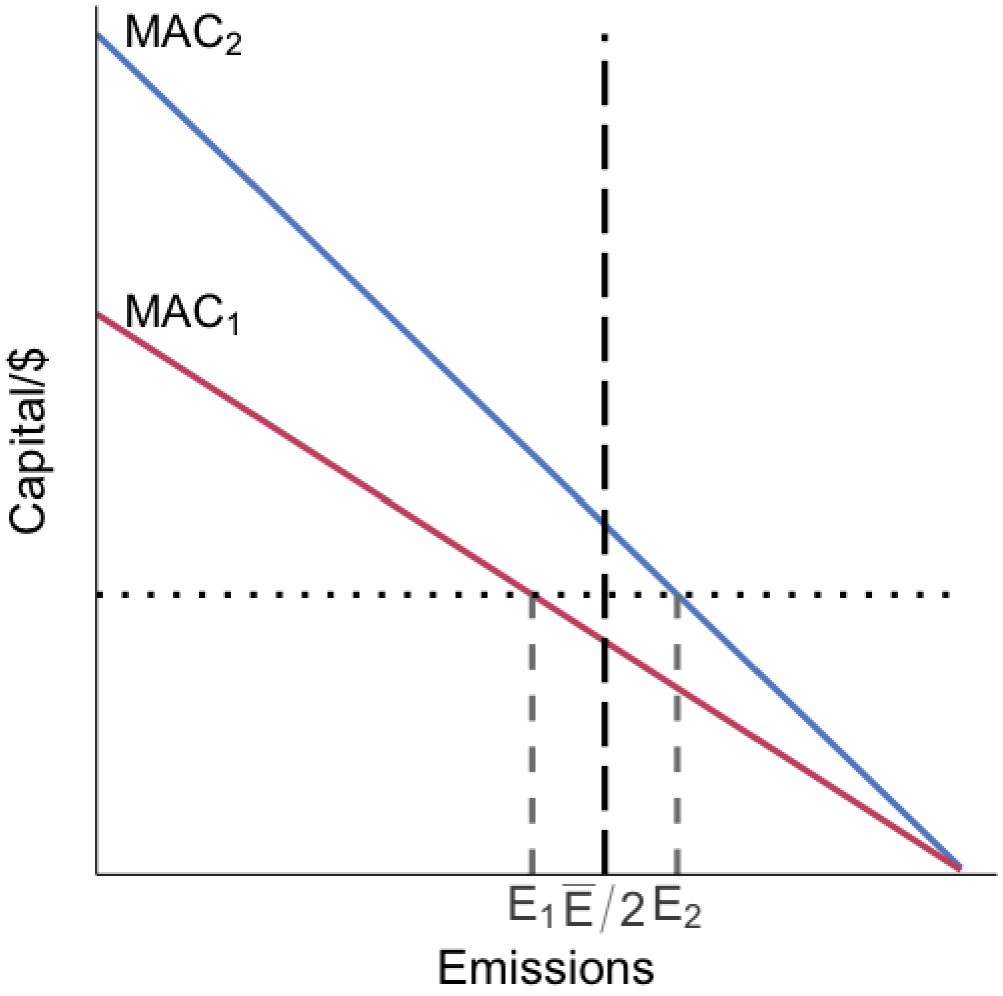
Let them trade the permits

Tradable permits: graphical



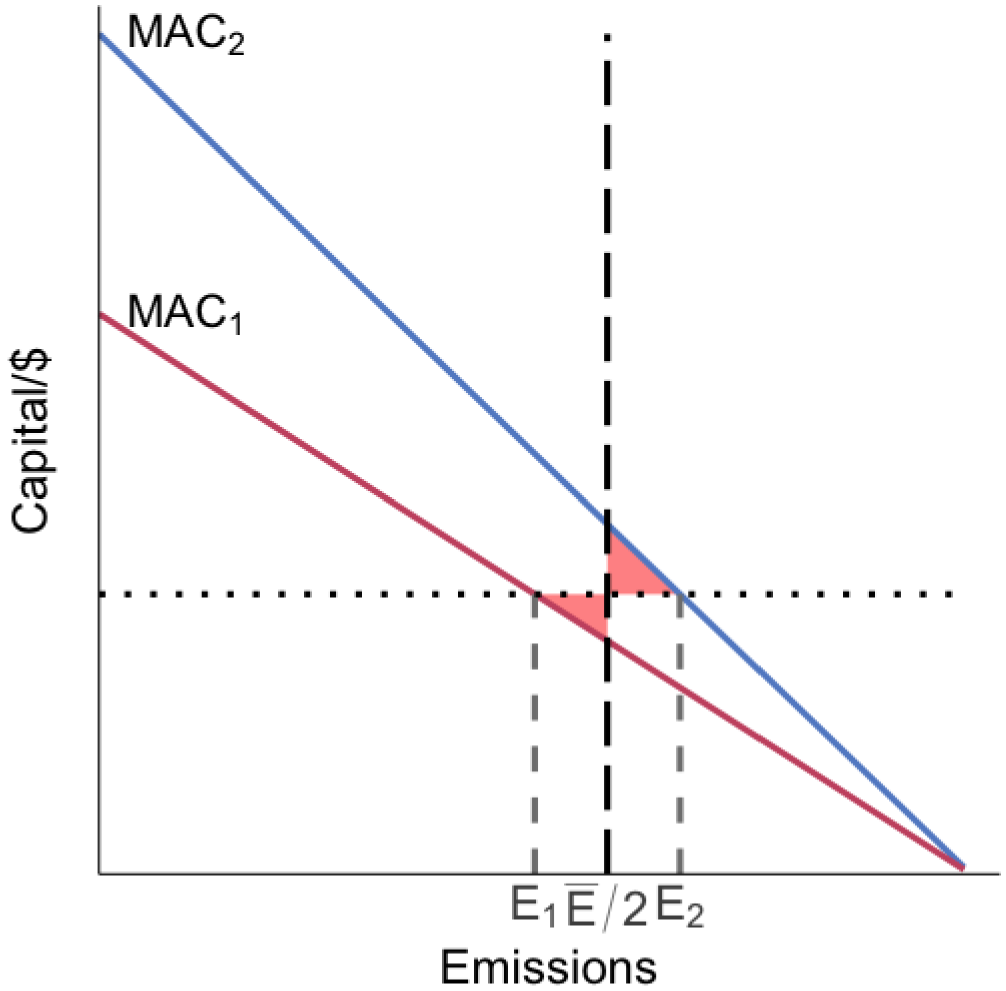
We can reduce costs by increasing abatement at which firm, and decreasing abatement at which firm?

Tradable permits: graphical



We can reduce costs by increasing emissions at high MAC firm 2 and decreasing emissions at low MAC firm 1 until they are equal

Tradable permits: graphical



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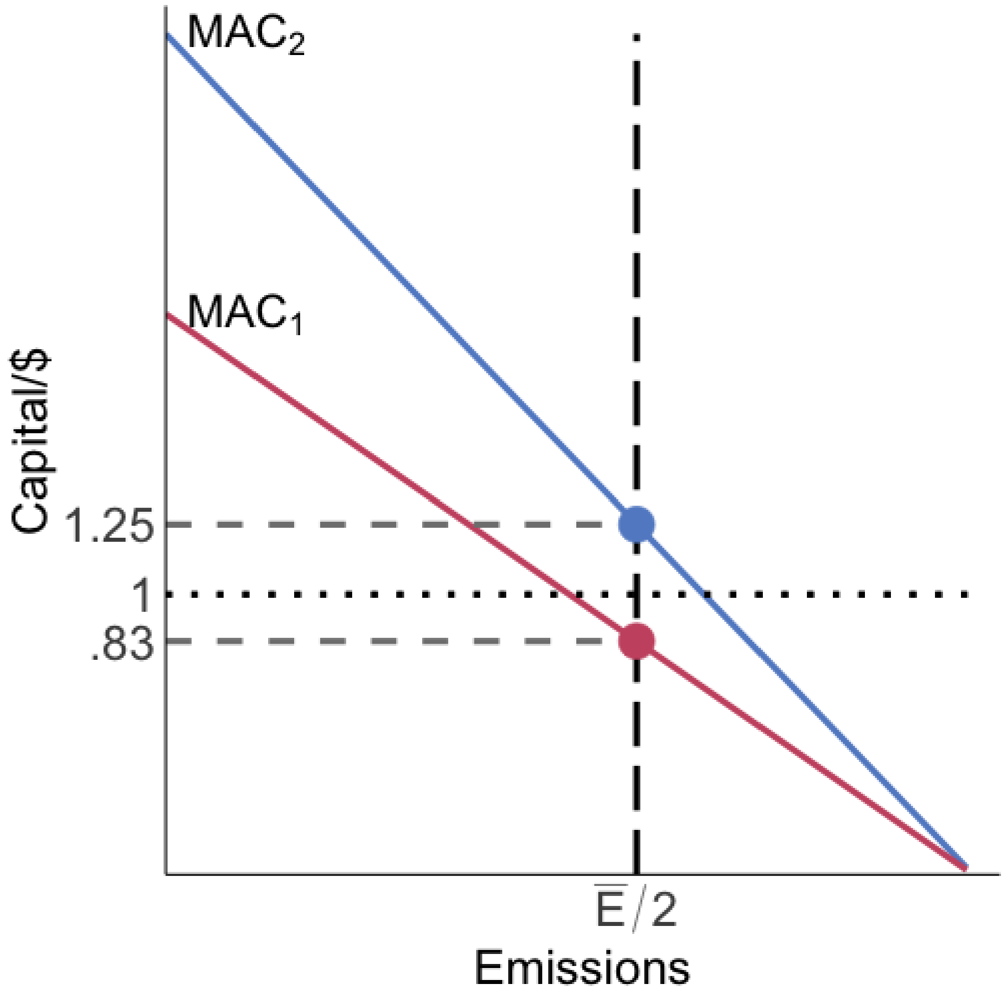
This allows us to recover DWL equal to the red area

The red area is the difference in areas under MAC2 and MAC1 over the range of emissions changes

Tradable permits: graphical



We want to equalize MACs for cost-effectiveness, but does the permit market cause this to happen?

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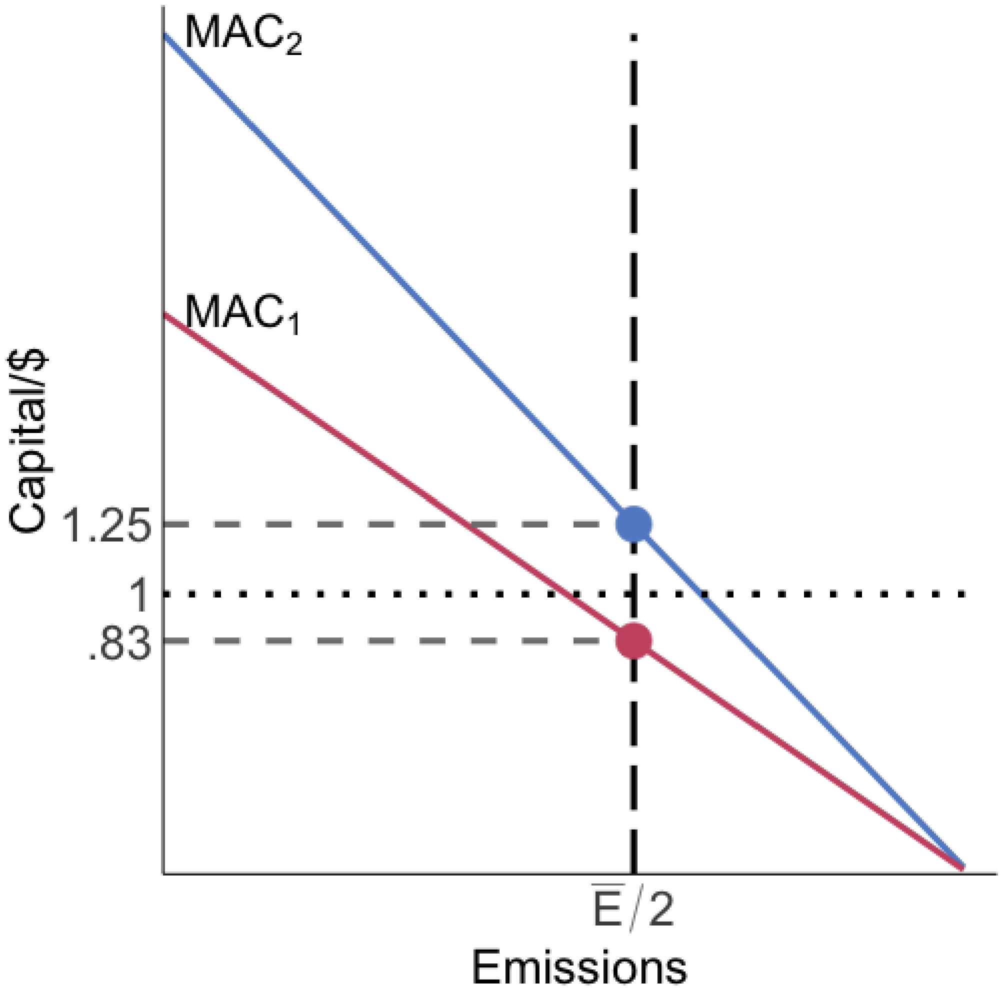
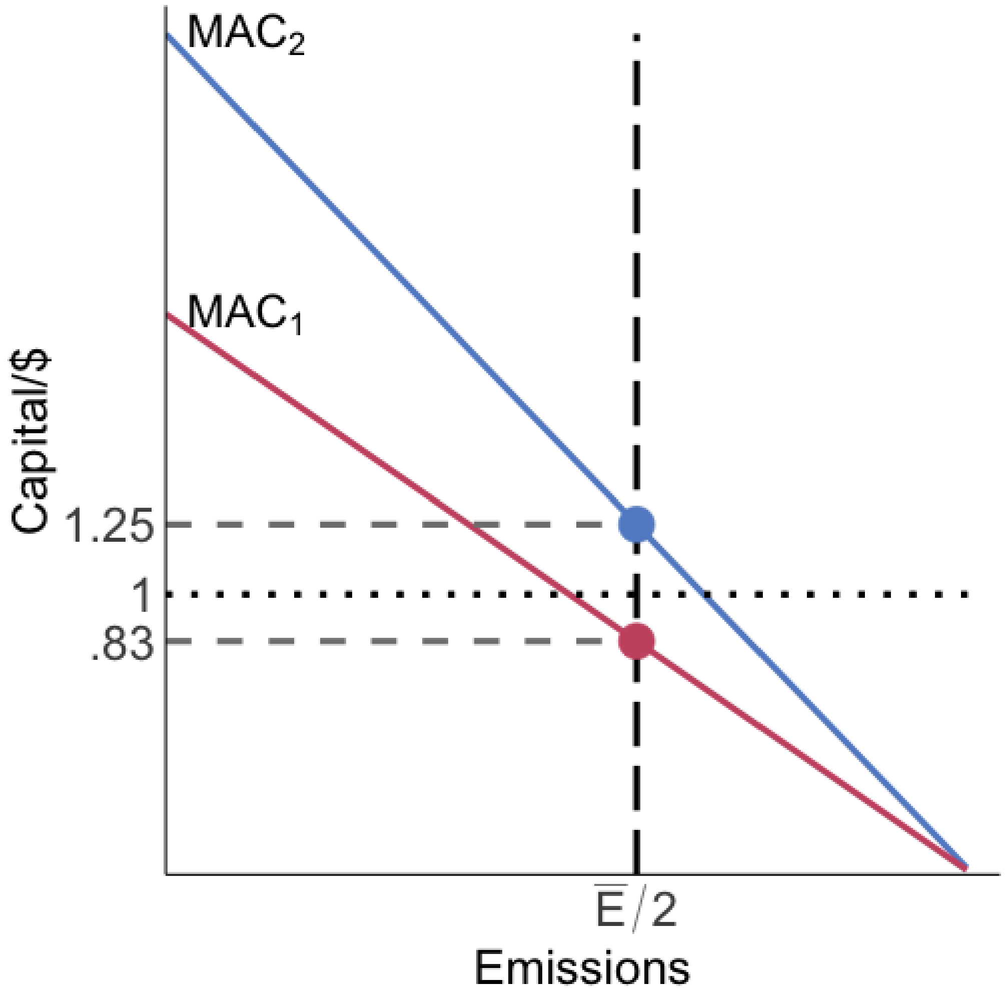


We want to equalize MACs for cost-effectiveness, but does the permit market cause this to happen?

Firm 2 is willing to pay a price up to the blue point (1.25) to be able to emit 1 more unit

Firm 1 can abate 1 more unit at cost equal to the red point (0.83)

Tradable permits: graphical

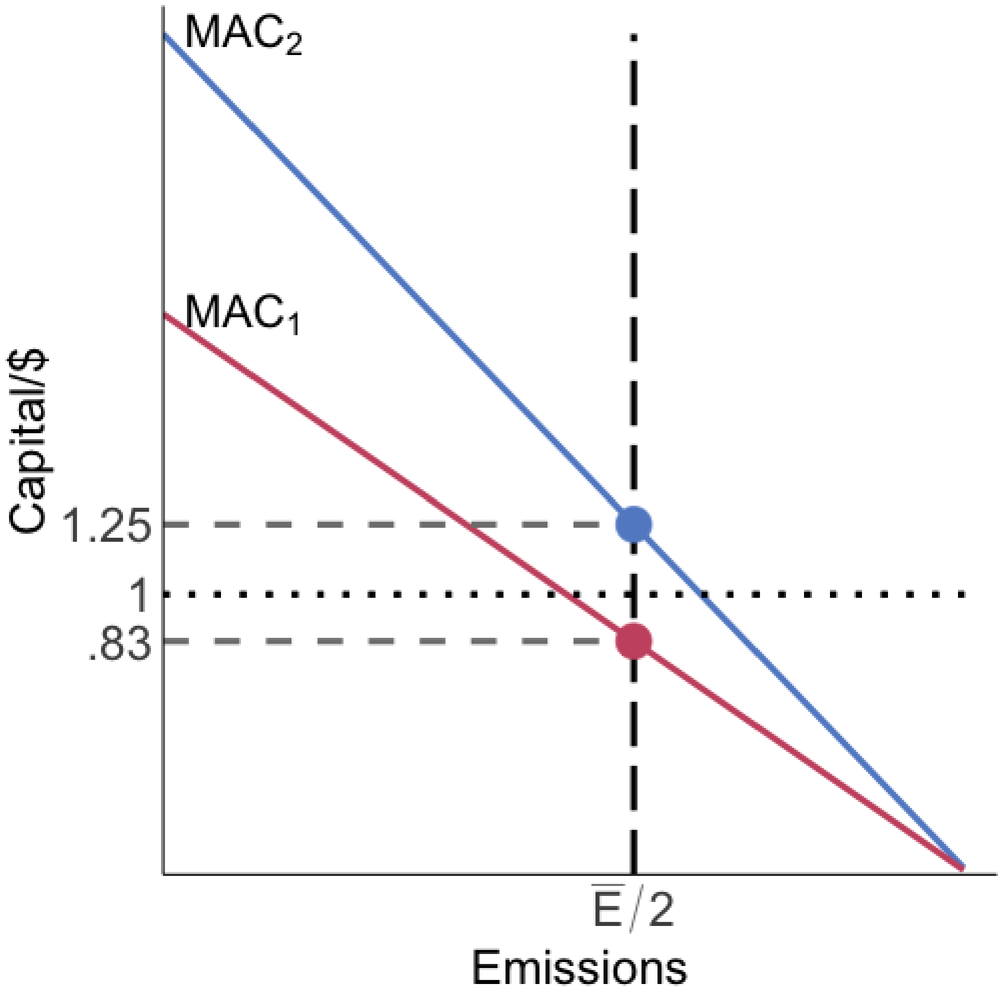


Firm 2 can buy the right to emit 1 unit of pollution from firm 1 for anywhere between 1.25 and 0.83 and **both will be better off** [very Coasean!]

These trades can be done until the MACs are equal at a value of 1

This would be the prevailing permit price in a tradable permit system

Tradable permits: graphical



An alternative way to think about it:

the prevailing permit price is the MC of freeing up one more unit, the MAC of the selling firm

or it is the MB of freeing up one more unit (avoided MAC), the MAC of the buying firm

Tradable permits: firm

We can also see this result mathematically

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Suppose there is a permit price p in the competitive tradable permit market

Firms are price-takers in the permit market

Let's set up the firm problem: they want to minimize the cost of satisfying the policy

Tradable permits: firm

The firm's problem is then:

$$\min_{E} C(E) + pE$$

The firm's first-order condition to minimize costs is:

$$-C'(E^*) = p$$

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The firm's first-order condition to minimize costs is:

$$-C'(E^*) = p$$

The firm minimizes costs by choosing emissions E^* so that its MAC equals the permit price

Tradable permits: cost-effectiveness

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The permit price is the MC of emitting, the MAC is the MB of emitting (reduced abatement cost)

Costs are minimized when these two things are equal

Tradable permits: cost-effectiveness

What else does firm behavior tell us about permits?

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If firms all set their MACs equal to p then all their MACs are equal to one another, **we have cost-effectiveness:**

$$-C_1'(E_1^*) = -C_2'(E_2^*) = \cdots = -C_N'(E_N^*) = p$$

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Taxes and permits both achieve cost-effectiveness

Why?

Because firms treat permit prices and a tax identically in decisionmaking

Tradable permits: cost-effectiveness

Tradable permit systems are **always** cost-effective: whatever emissions limit you set, it will be achieved at least-cost[1]

[1] Try to see if you can use the same mathematical derivation to show that taxes are also always cost-effective.

Tradable permits: cost-effectiveness

Tradable permit systems are **always** cost-effective: whatever emissions limit you set, it will be achieved at least-cost[1]

This does not mean that it is necessarily efficient!

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Tradable permits: efficiency

For efficiency, we also need MAC = MD

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To keep things simple suppose MD is constant and the same across all firms:

$MD = d$

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To keep things simple suppose MD is constant and the same across all firms: $MD = d$

If we can set $\bar{E}$ such that the equilibrium permit price $p = d$, then we also have efficiency

Tradable permits in practice

Knowing MD is often difficult in practice

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Tradable permit systems are nice because we can just let politicians choose a $\bar{E}$ that is politically feasible, and then the permit market ensures that we get the associated emissions reductions at least-cost

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Tradable permit systems are nice because we can just let politicians choose a $\bar{E}$ that is politically feasible, and then the permit market ensures that we get the associated emissions reductions at least-cost

What often happens in practice is $\bar{E}$ starts high, giving us a low p, and then $\bar{E}$ gets ratcheted down over time

Political economy of permits

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This is one of the key reasons the 1990 CAA amendments were able to be passed

Permit market challenges

How we do initially allocate permits?

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Lottery: Randomly assign permits

Grandfathering: give permits to existing firms based on historical emissions

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We can decentralize trading market to cut down on transaction costs

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Do trades need to be validated by central authority to ensure permit validity?

Permit market challenges

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Search, information, bargaining, monitoring/enforcement

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Examples?

Search, information, bargaining, monitoring/enforcement

Lots of these costs are fixed, prohibit small trades

Permit systems and heterogeneous MDs

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This is true for things like climate change, less true for things like SO_2 or NO_x

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How well do permit systems perform with heterogeneous MD?

Permit systems and heterogeneous MDs

Let's think about a setting with two firms: 1 and 2

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And the firms have different marginal damages as well: $MD_1 < MD_2$ for all E

Permit systems and heterogeneous MDs

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And the firms have different marginal damages as well: $MD_1 < MD_2$ for all E

How well does a permit system work?

Permit systems and heterogeneous MDs

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But for efficiency we also want $MAC = MD$: $MAC_1 = MD_1$ and $MAC_2 = MD_2$

Permit systems and heterogeneous MDs

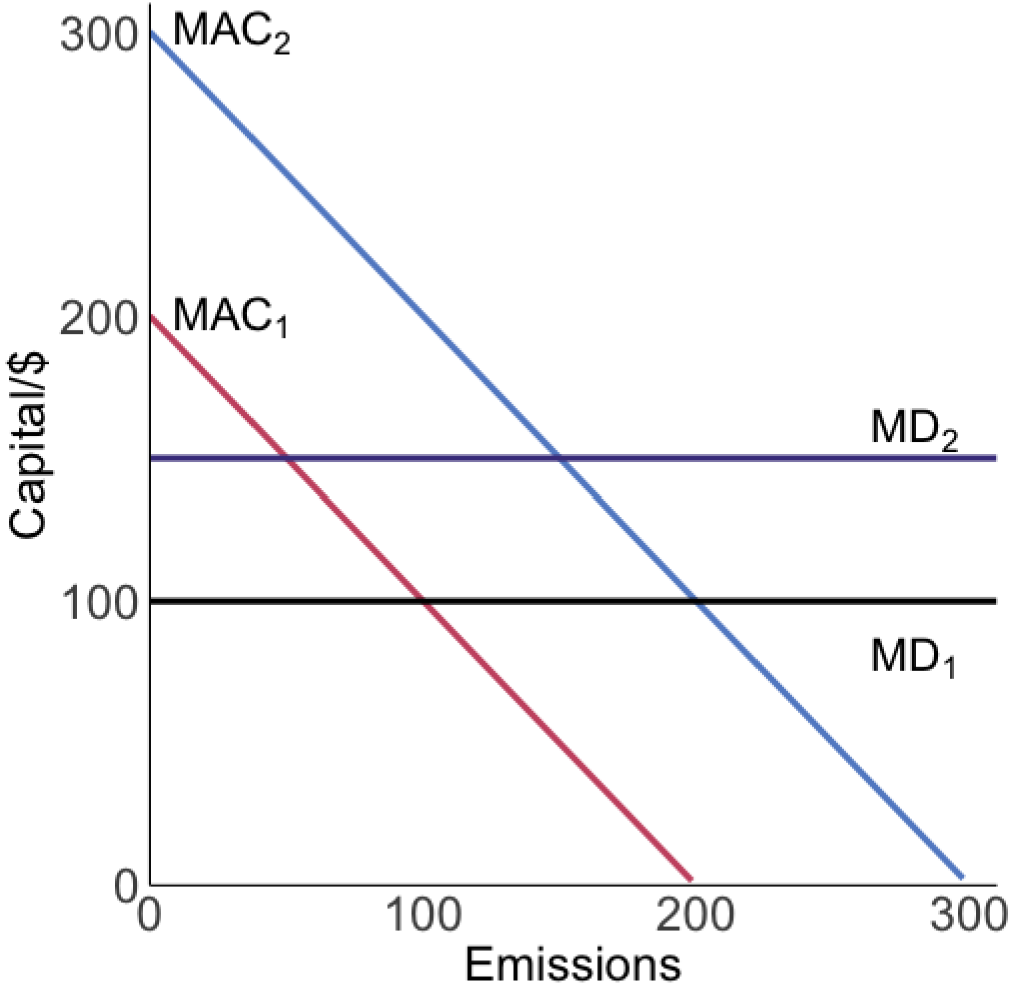
Well we know the following:

Firms set $MAC = p$ so we will have $MAC_1 = MAC_2 = p$

But for efficiency we also want $MAC = MD$: $MAC_1 = MD_1$ and $MAC_2 = MD_2$

If $MD_1 \neq MD_2$ then the permit system does **not** deliver efficiency!

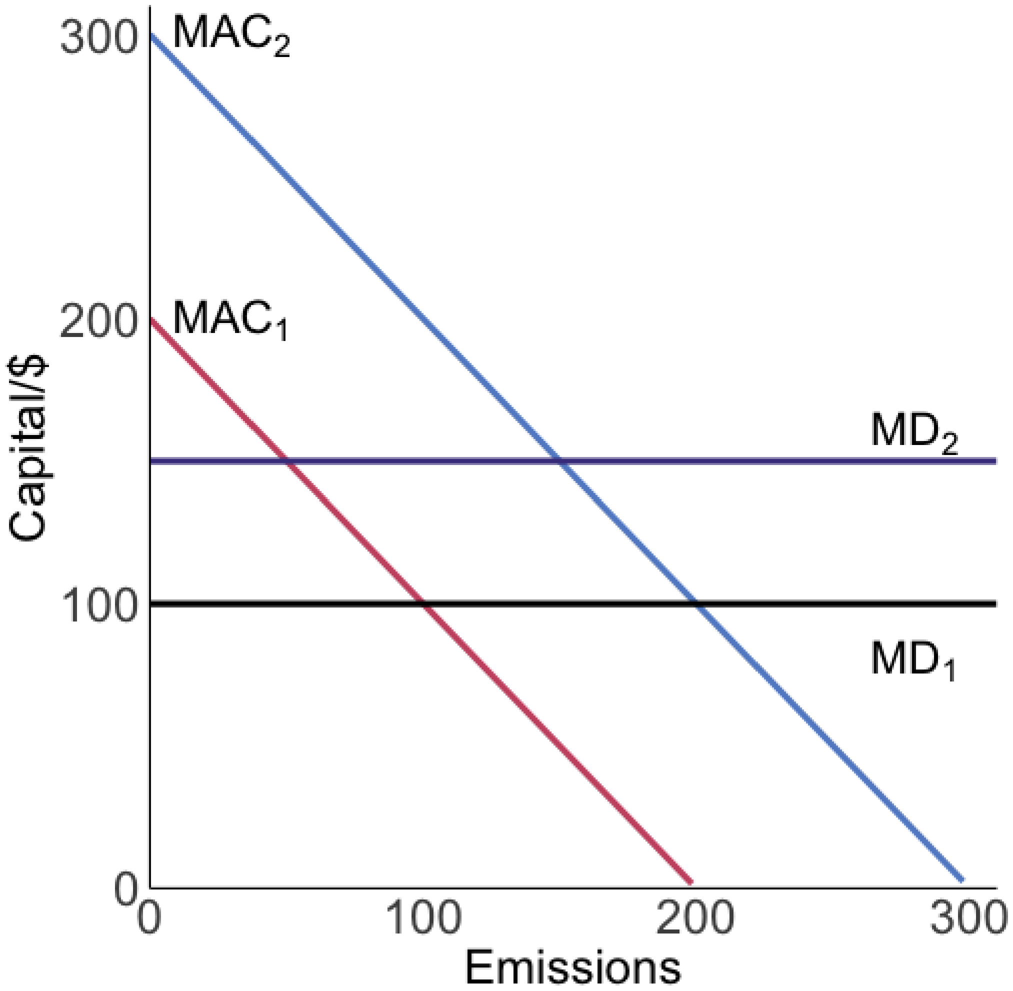
Permit systems and heterogeneous MDs: graphical



Suppose we have the two firms with different MACs and MDs:

- $MAC_1 = 200 - E_1$
- $MAC_2 = 300 - E_2$
- $MD_1 = 100$
- $MD_2 = 150$

Permit systems and heterogeneous MDs: graphical



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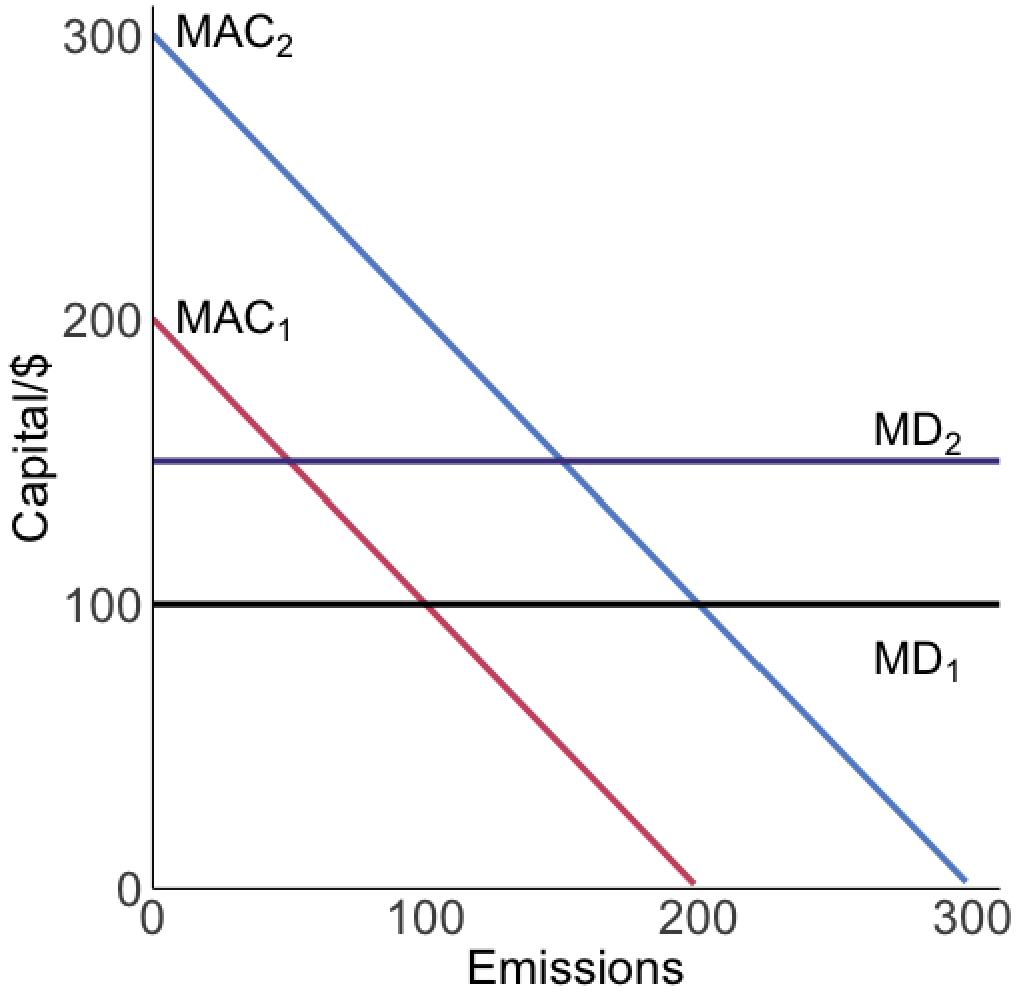
- $MAC_2 = 300 - E_2$
- $MD_1 = 100$
- $MD_2 = 150$

The efficient emissions allocation is: $E^* = 250 : E_1^* = 100, E_2^* = 150$

The regulator sets $\bar{E} = 250$

Permit systems and heterogeneous MDs: graphical



We can solve for the permit market allocation and price using:

$MAC_1 = MAC_2$ and

$E_1 + E_2 = 250$

These two conditions tell us:

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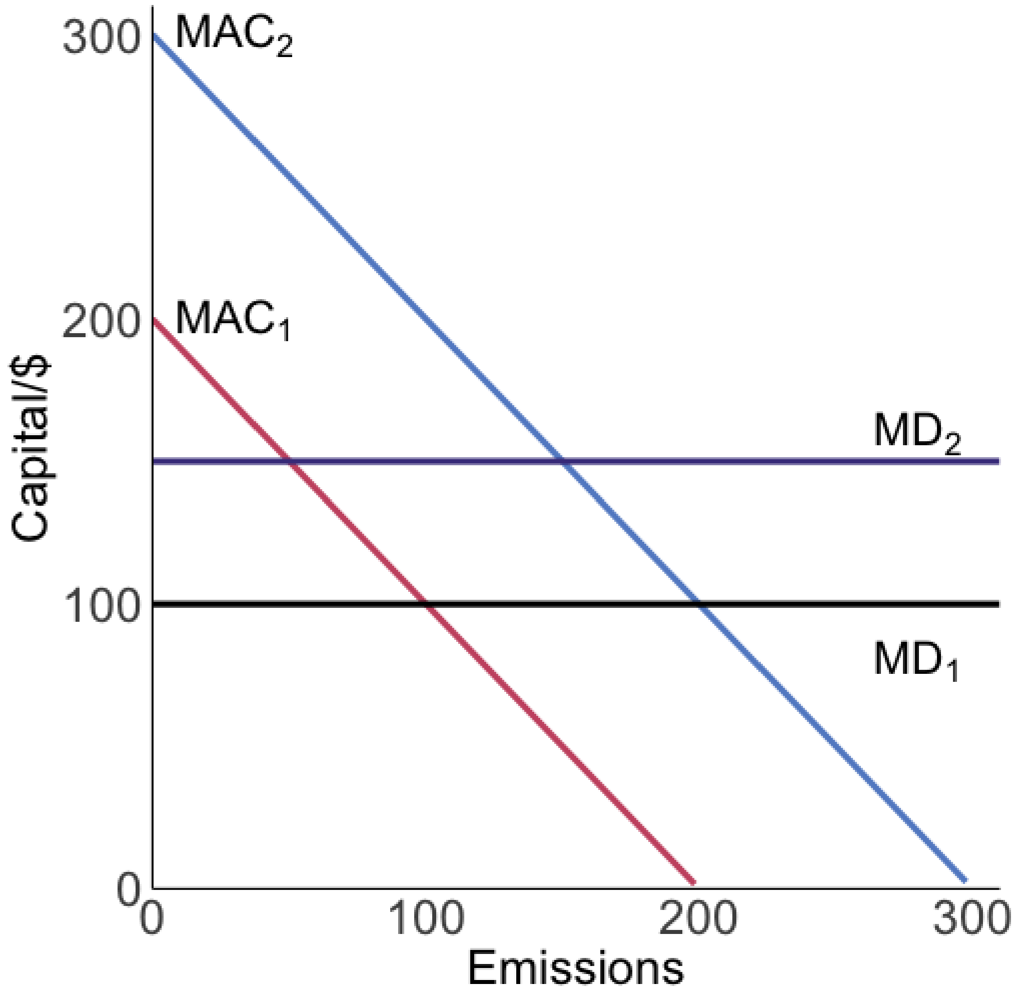


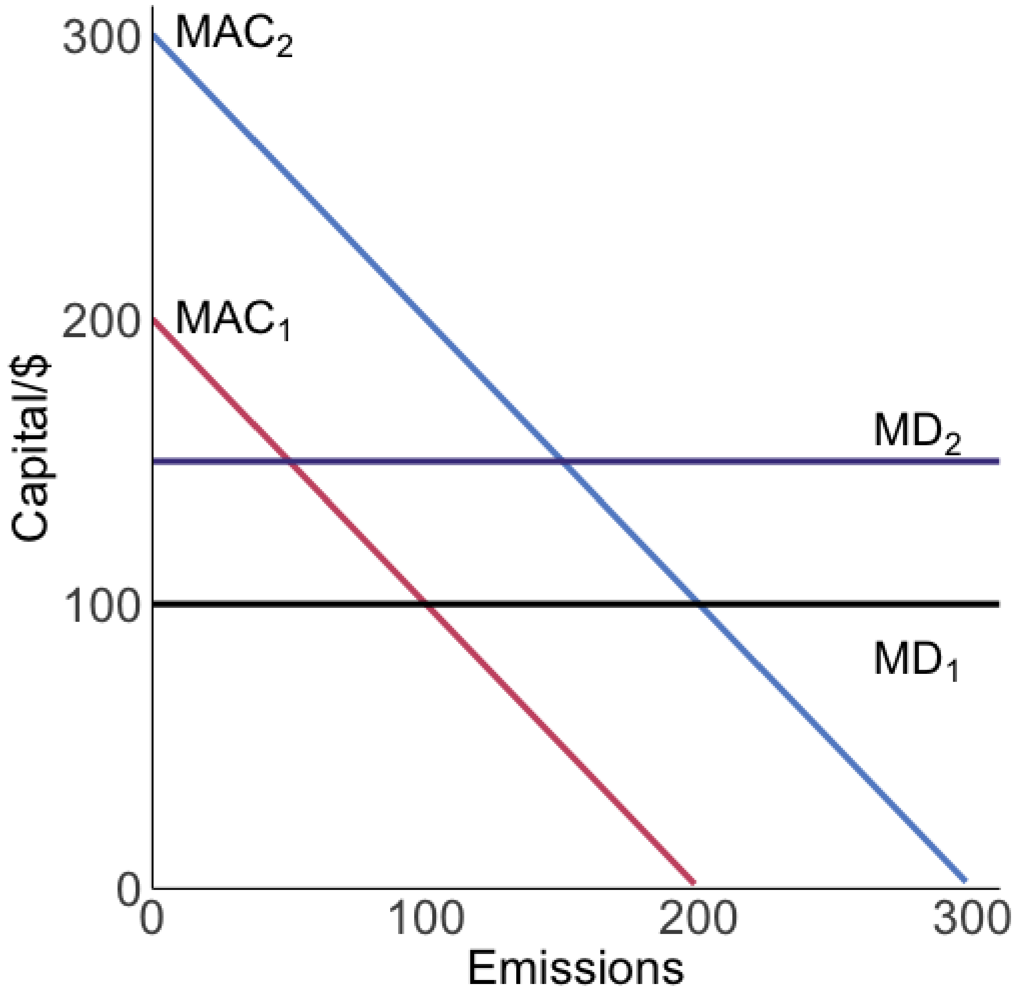
We can solve for the permit market allocation and price using: $MAC_1 = MAC_2$ and $E_1 + E_2 = 250$

These two conditions tell us:

$E_1^p = 75, E_2^p = 175, p = 125$

but efficiency is at:

Permit systems and heterogeneous MDs: graphical



We can solve for the permit market allocation and price using:

$MAC_1 = MAC_2$ and

$E_1 + E_2 = 250$

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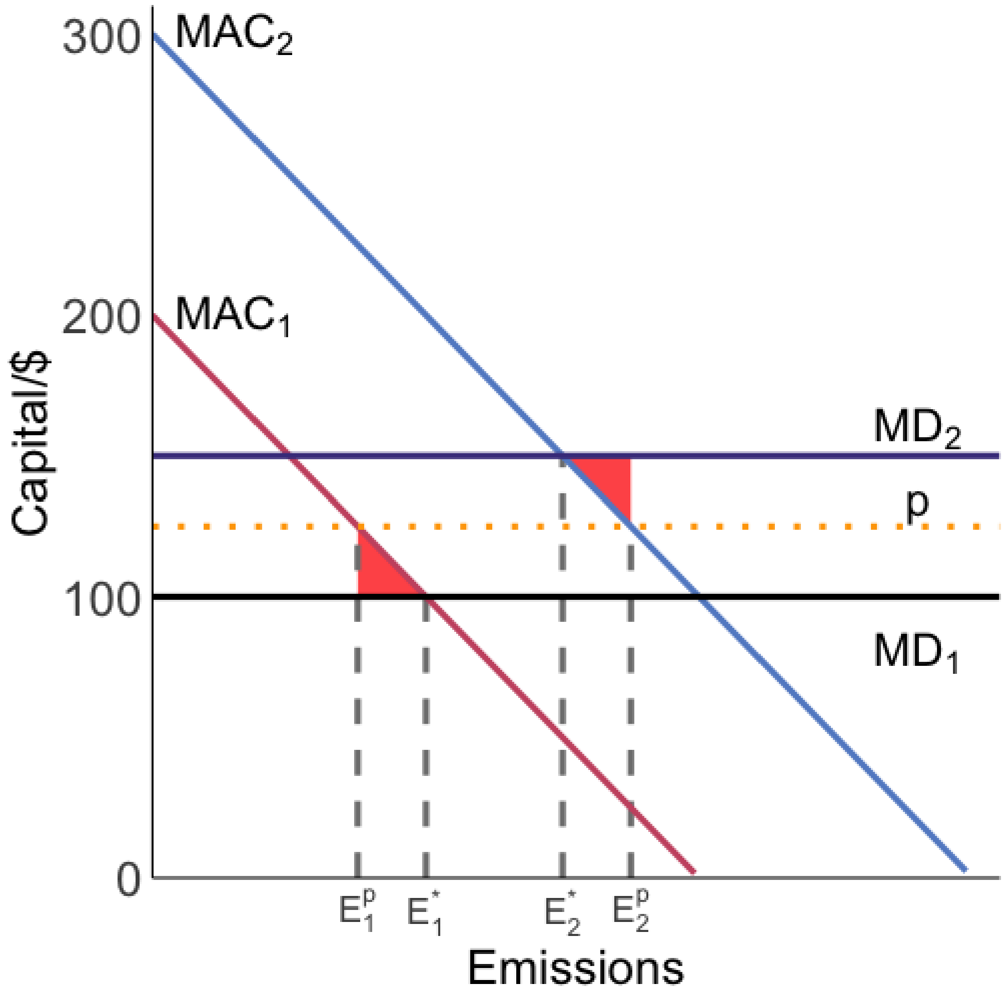

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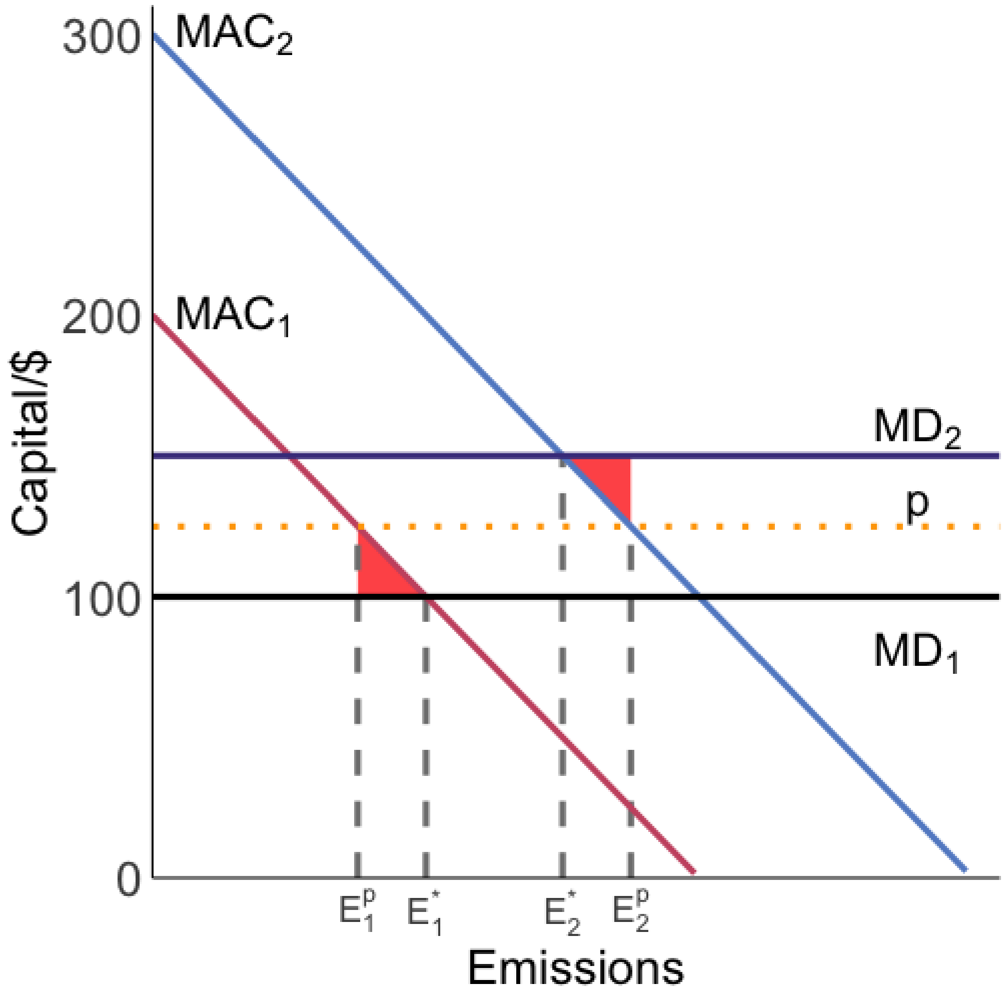
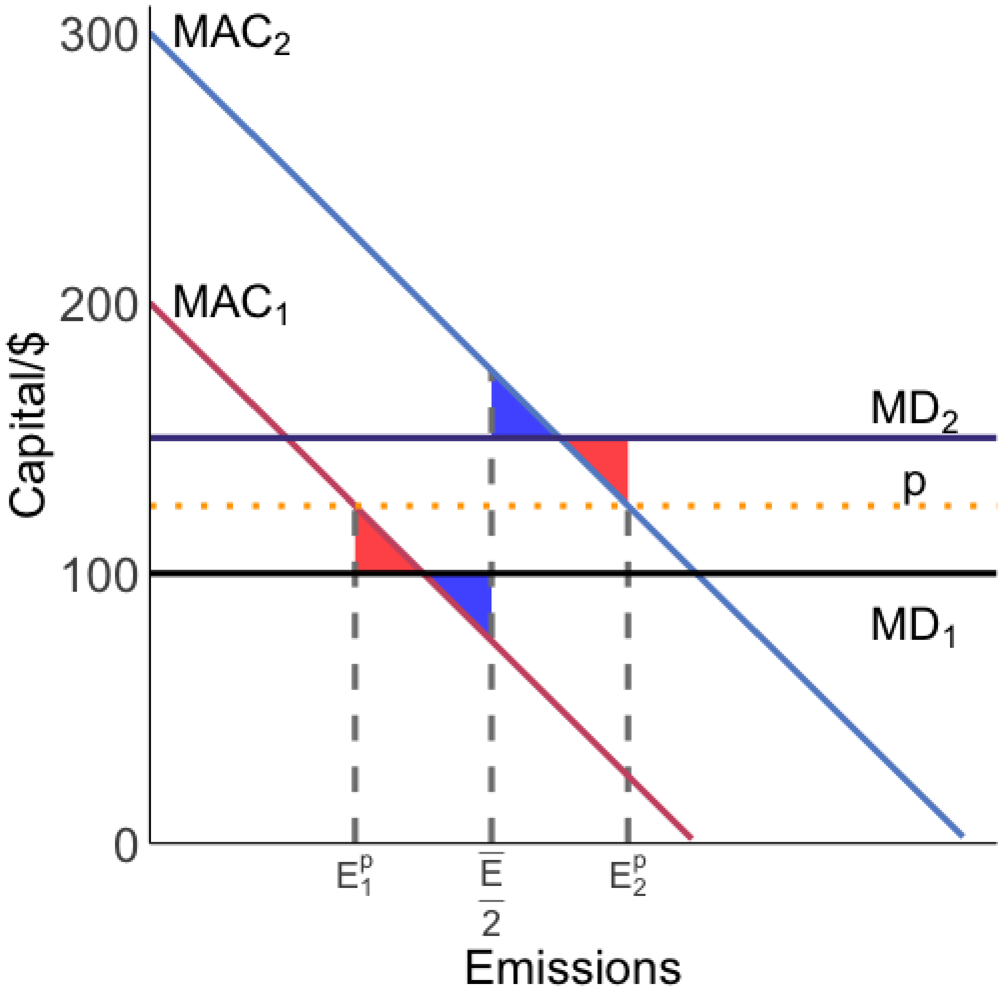


Relative to the optimal allocation, the permit system has DWL equal to the **red area**

The permit allocation is not an **efficient** allocation, but is it a **Pareto improvement** over:

1. No policy?
2. A uniform standard of $\bar{E}/2$?

Permit systems and heterogeneous MDs: graphical

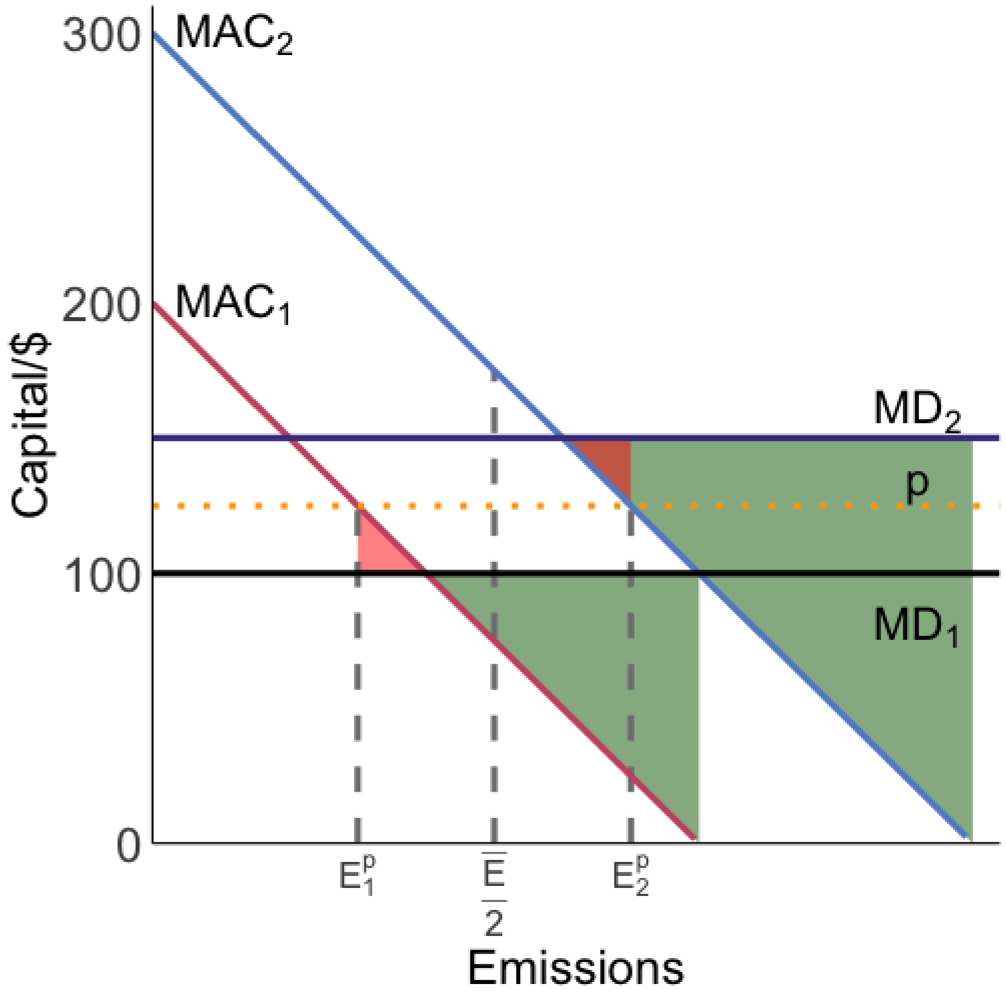


The blue area is the DWL under the uniform standard

In this specific case, a uniform standard and the permit system have the same efficiency since the red and blue areas are equal

The only difference is what kind of welfare loss is occurring where

Permit systems and heterogeneous MDs: graphical

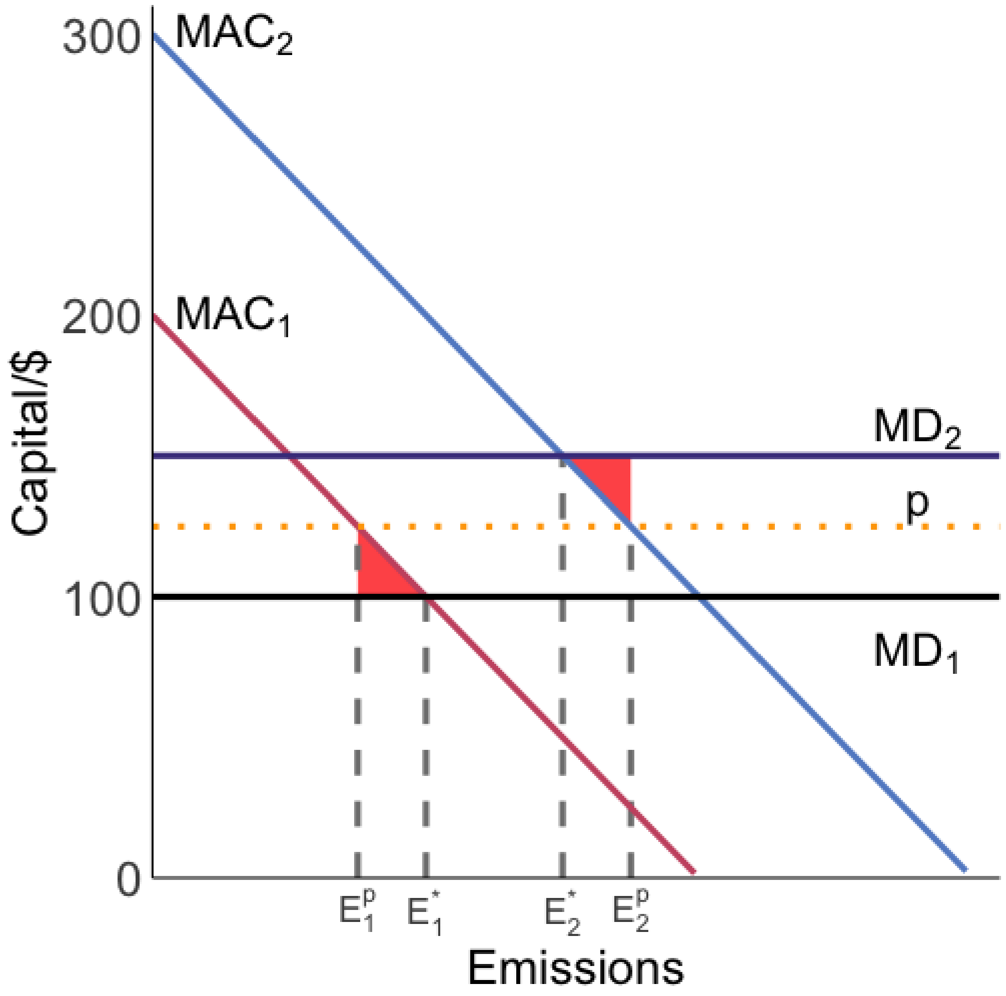


The DWL without any policy is the two large green triangles

These are clearly larger than the DWL under the permit system

The permit system can deliver a welfare improvement

Permit systems and heterogeneous MDs: graphical



What if the high MAC firm was the low MD firm?

i.e: what if the correlation between MAC and MD was **negative** instead of **positive**?

What might we expect the correlation to be?

Permit systems and heterogeneous MDs

What is the problem with permit systems and heterogeneous MD?

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One way around this is to use **trading ratios**: firms in high damage areas need to procure more permits for the same amount of emissions

Another way is **zonal trading**: firms can only trade in similar MD areas

Trading ratios: Acid Rain Program

Below are estimates of efficient trading ratios for the Acid Rain Program

TABLE 3—TRADING RATIOS BETWEEN SOURCES AT EACH QUANTILE FOR SO_2

Quantile	Source location (county, state)	1st	25th	50th	75th	99th	99.9th
1st	Josephine, OR	1.0	0.4	0.2	0.2	0.1	0.02
25th	Polk, TX	2.5	1.0	0.6	0.4	0.1	0.1
50th	Grant, AR	4.5	1.8	1.0	0.7	0.2	0.1
75th	Marion, SC	6.0	2.4	1.3	1.0	0.3	0.1
99th	Allegheny, PA	19.2	7.7	4.3	3.2	1.0	0.4
99.9th	Hudson, NJ	49.4	19.6	11.0	8.2	2.5	1.0

Note: The trading ratio represents the number of tons from the column source required to offset one ton from the row source.

Muller and Mendelsohn (2009)

PM2.5 damages

Trading ratios are required because damages are heterogeneous across space

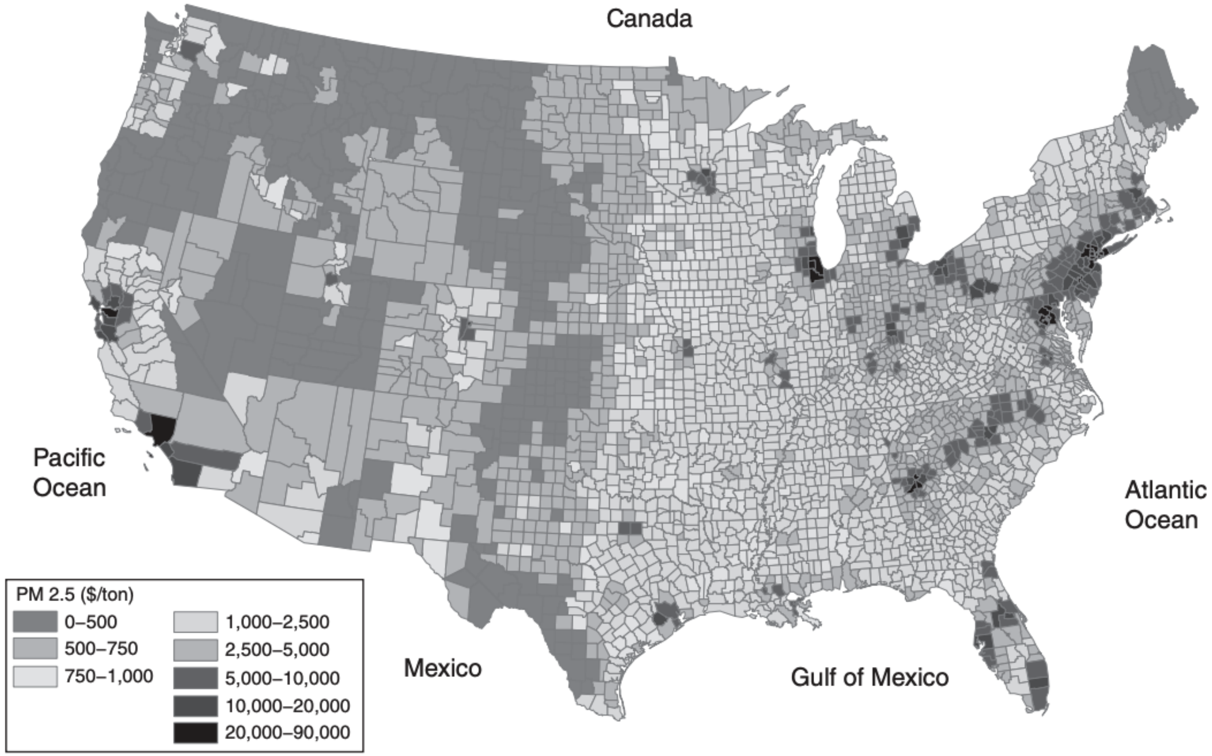
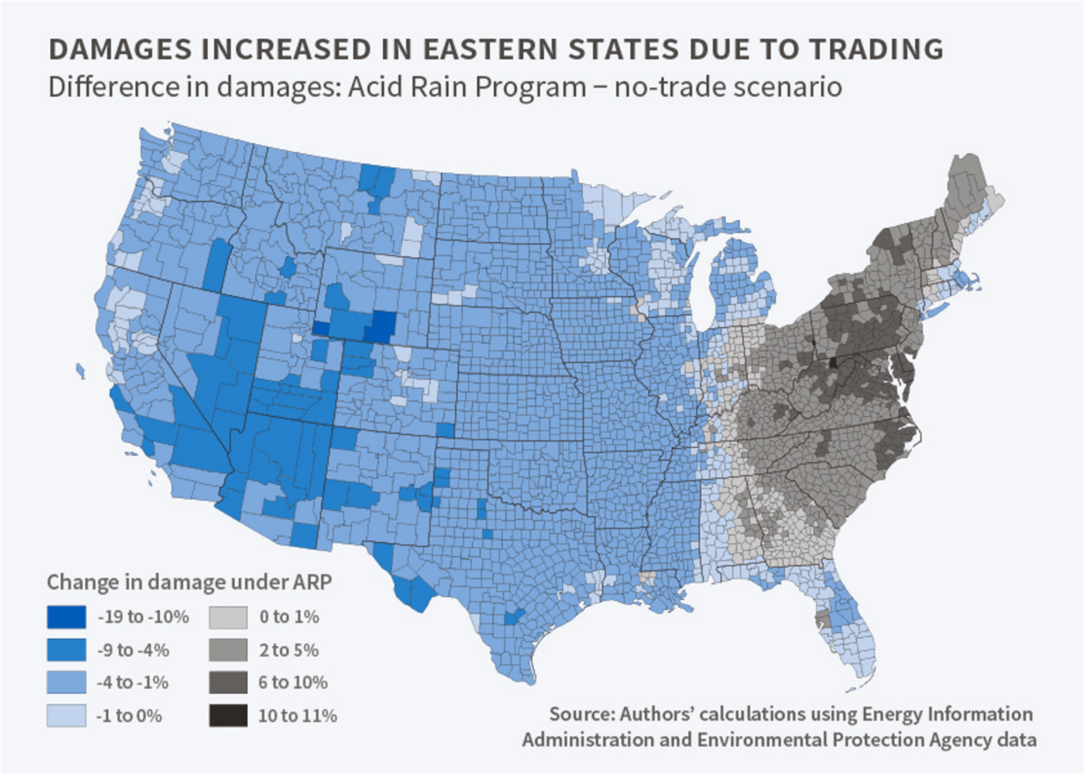


FIGURE 1. MARGINAL DAMAGE OF EMISSIONS FOR GROUND LEVEL SOURCES OF $PM_{2.5}$ ($/TON/YEAR)

Damages caused by ARP

The Acid Rain Program **increased** damages in the eastern US



Chan et al. (2018)

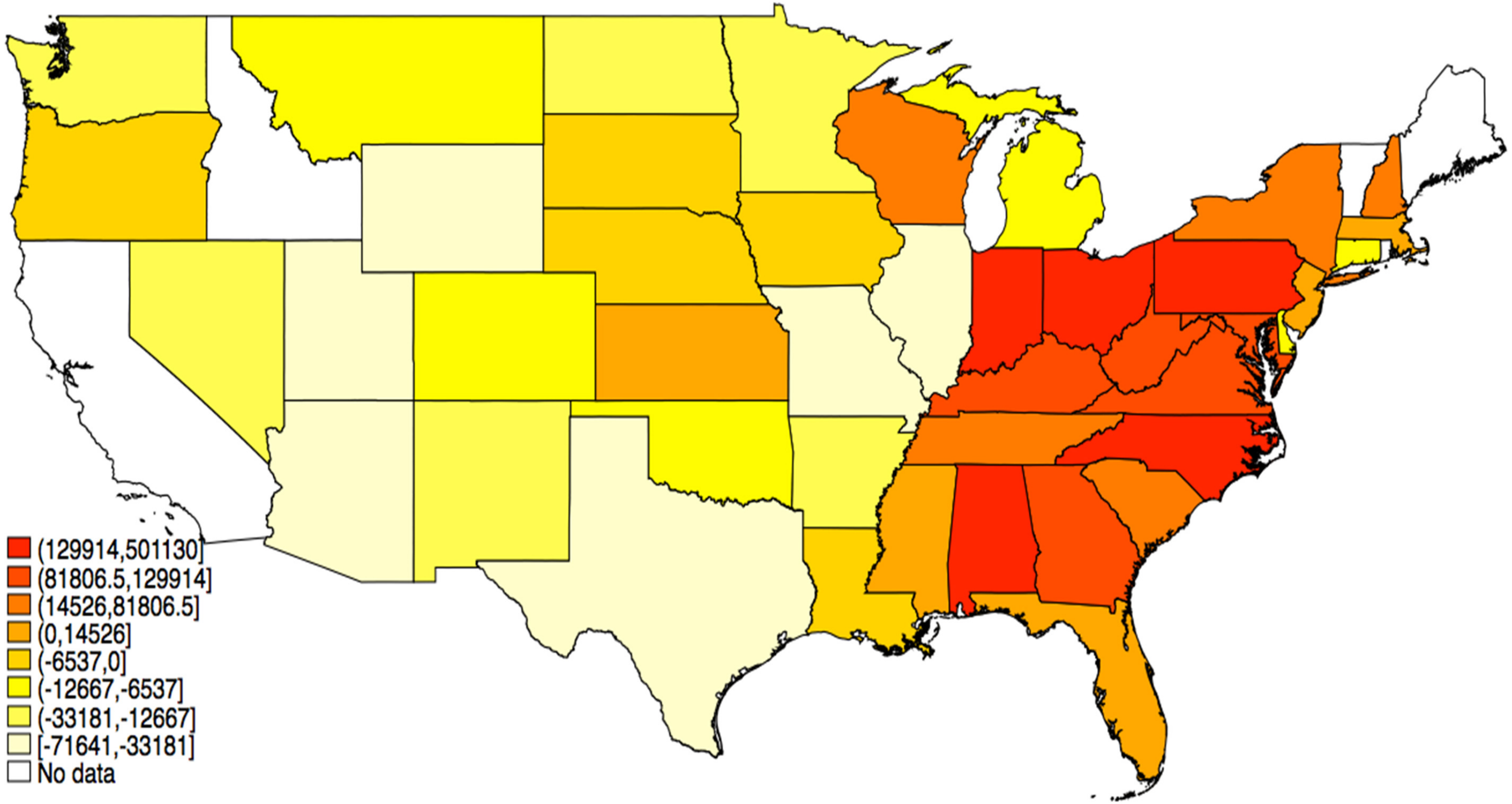
Damages caused by ARP

Chan et al. (2018) JEEM:

> We also compare health damages associated with observed SO2 emissions from all ARP units in 2002 with damages from a no-trade counterfactual. Damages under the ARP are $2.1billion(1995$) higher than under the no-trade scenario, reflecting allowance transfers from units in the western US to units in the eastern US with larger exposed populations.

Damages caused by ARP

Redder: trading lead to greater emissions vs no trading



Zonal trading: RECLAIM

Regional Clean Air Management (RECLAIM) Program

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California South Coast Air Quality Management District (SCAQMD)

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RECLAIM is a facility-level tradable permit system

Zonal trading: RECLAIM

14% of permits allocated to power generators

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Permit prices driven by electricity sector

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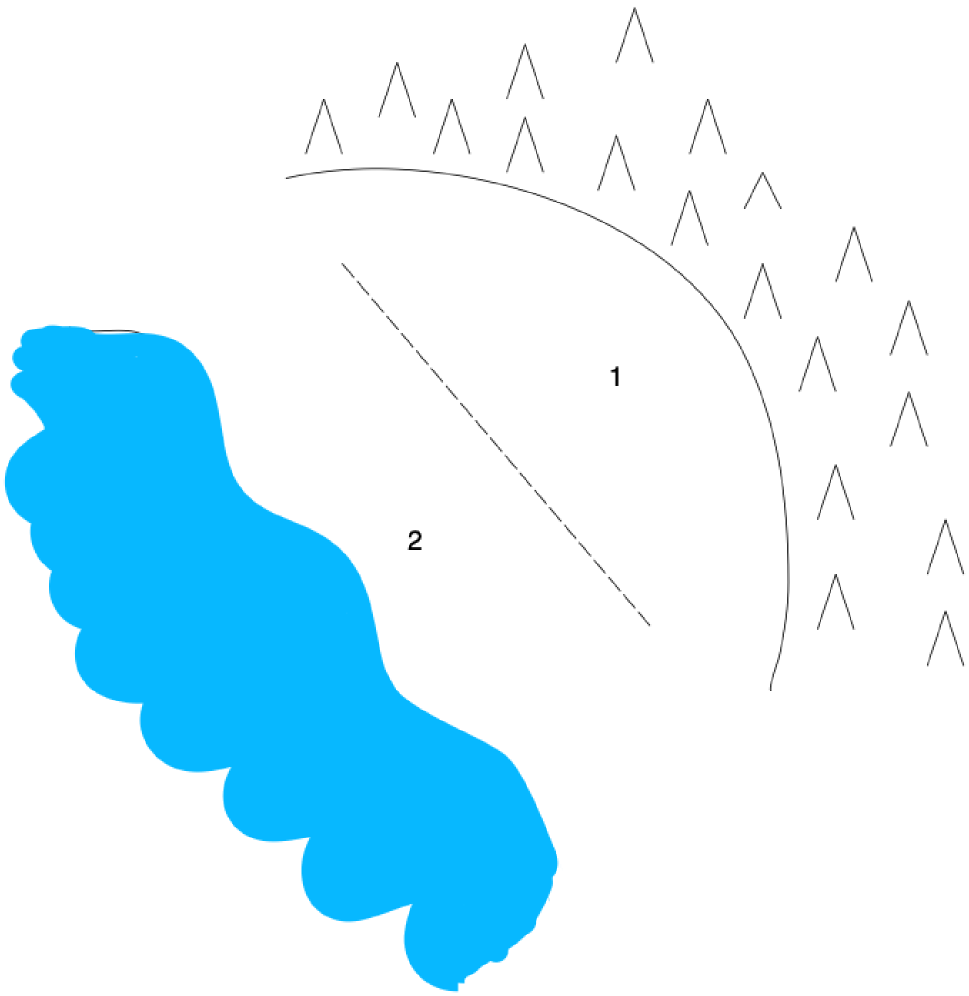
$39,000 per ton of NOx in 2000

Zonal trading: RECLAIM



LA Basin has two distinct zones with very different MD's

1. Old heavy industry (high MAC) and mountains trap NOx emissions and heat them up $\rightarrow$ smog (high MD)

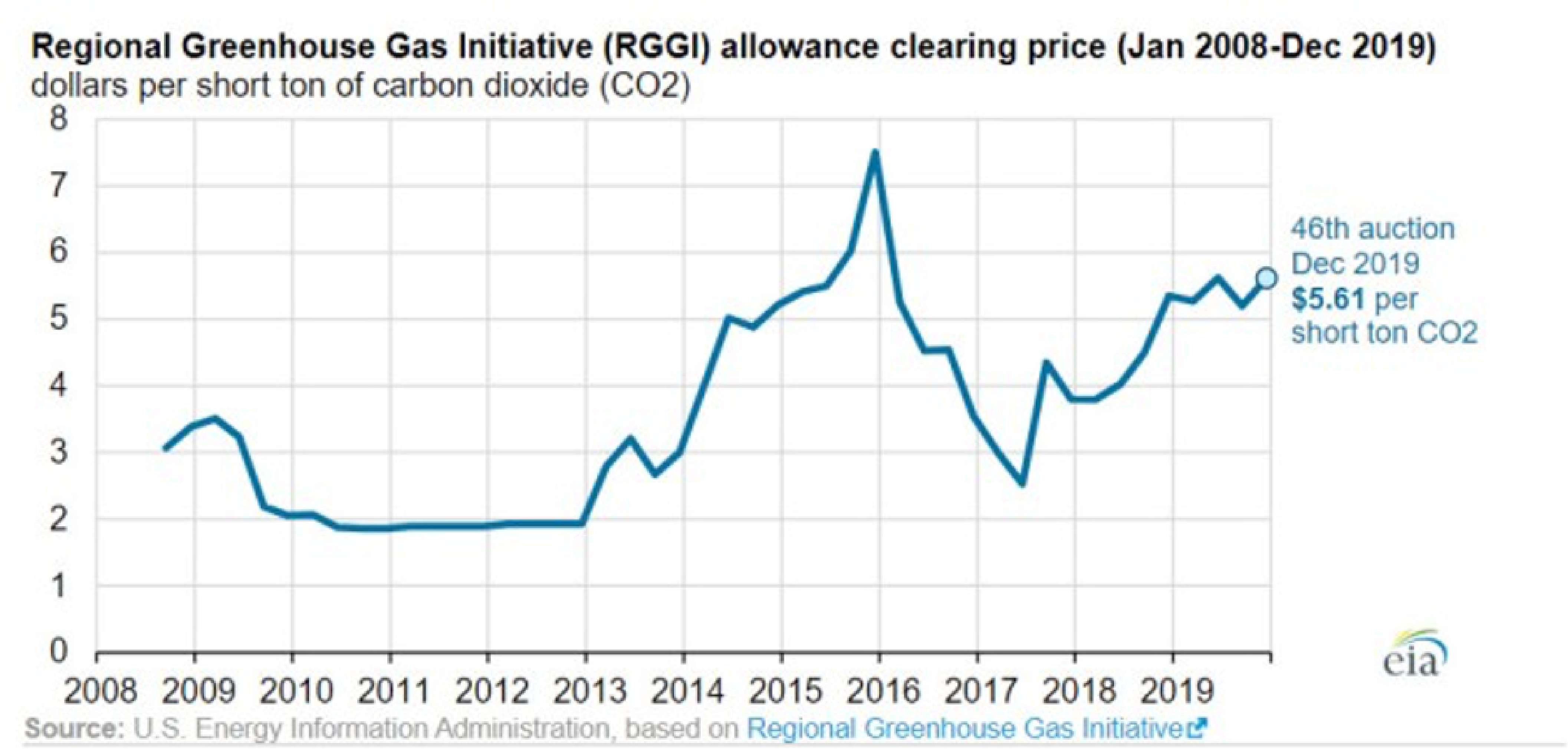
2. Newer firms (low MAC) close to the ocean, breezes dissipate pollution before it can turn into smog (low MD)

Other permit market examples

Tradble permit systems are increasingly common:

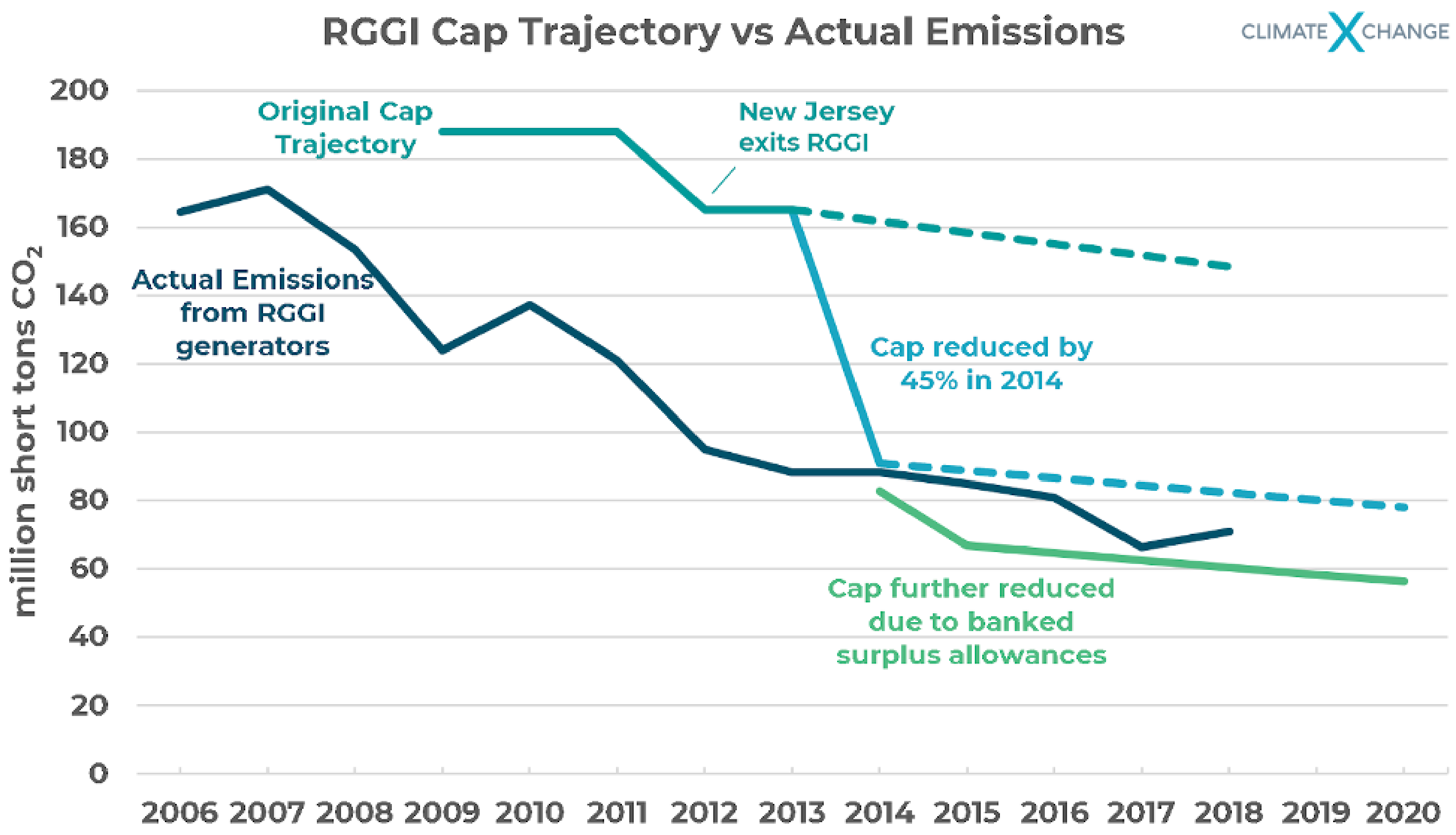
1. Acid Rain Program
2. NOx Budget Program
3. Regional Greenhouse Gas initative
4. California AB32
5. EU Emission Trading System
6. China's National Carbon Cap and Trade

RGGI



Regional Greenhouse Gas Initiative (RGGI) allowance clearing price (Jan 2008-Dec 2019)
dollars per short ton of carbon dioxide (CO2)
8
7
6
5
4
3
2
1
0
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
46th auction
Dec 2019
$5.61 per
short ton CO2
Source: U.S. Energy Information Administration, based on Regional Greenhouse Gas Initiative

RGGI

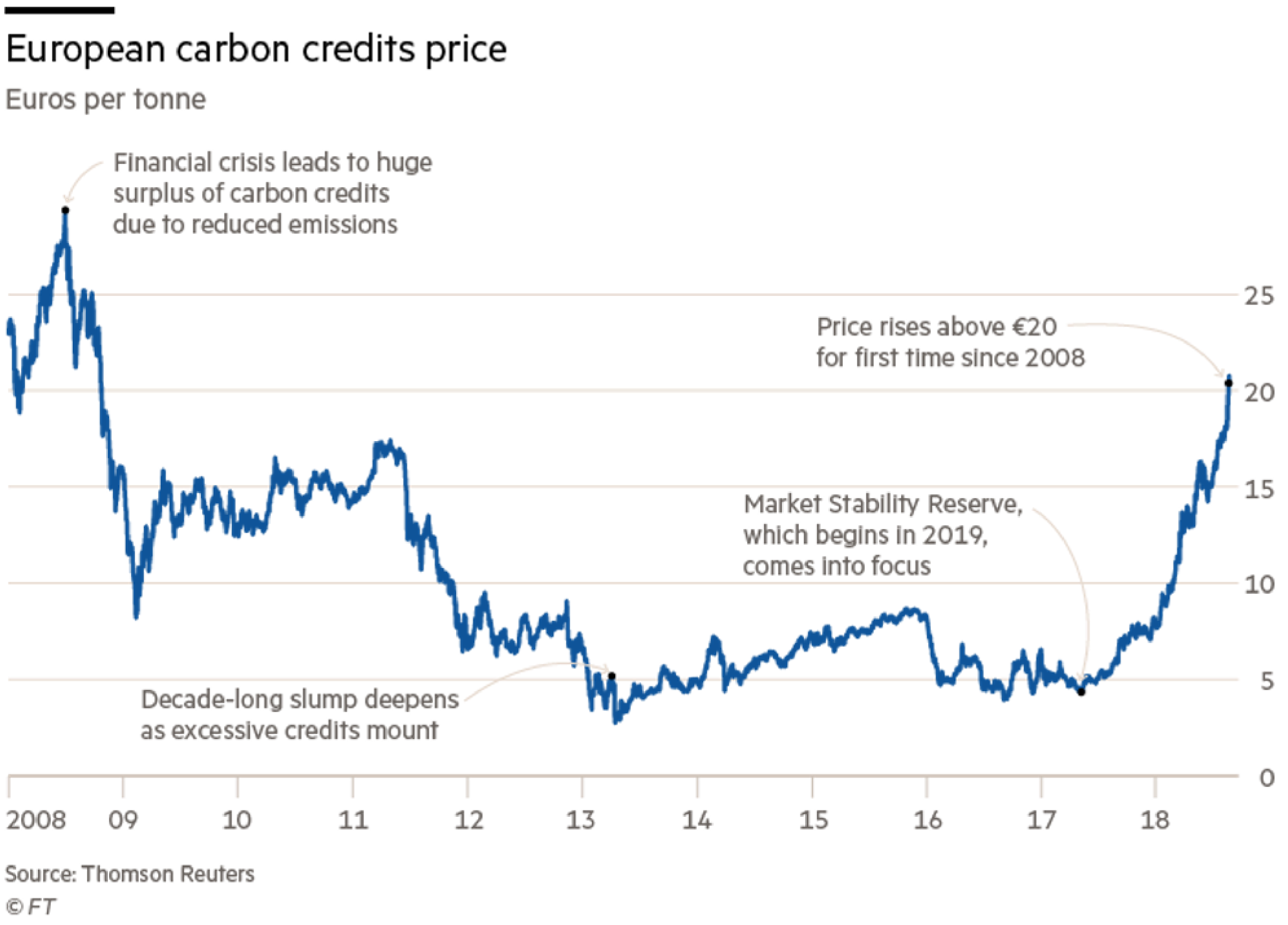


RGGI Cap Trajectory vs Actual Emissions
CLIMATE X CHANGE
200
180
160
140
120
100
80
60
40
20
0
million short tons CO_2
Original Cap Trajectory
New Jersey exits RGGI
Actual Emissions from RGGI generators
Cap reduced by 45% in 2014
Cap further reduced due to banked surplus allowances
2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

AB32

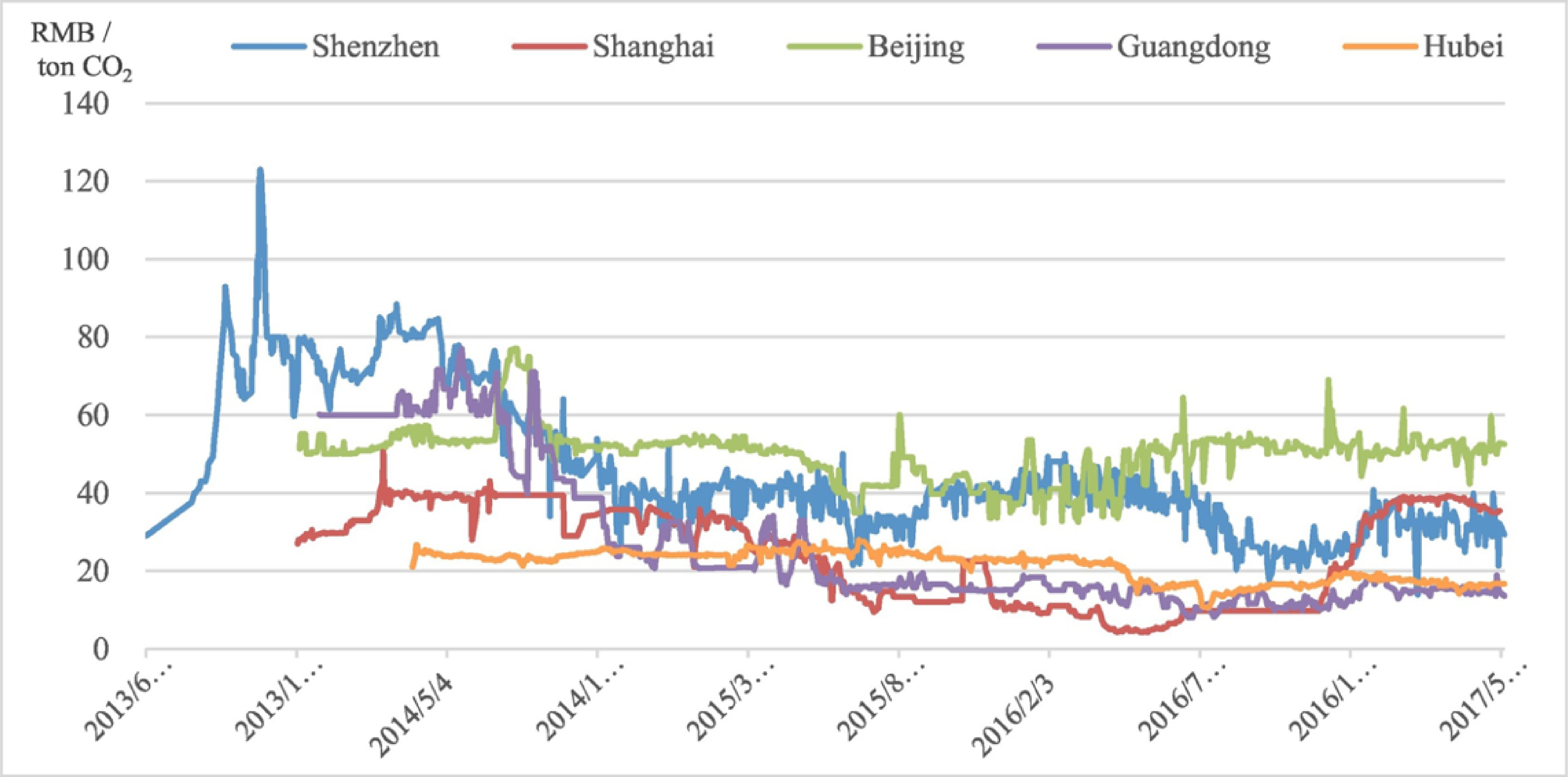
CARBON PRICE
$/Tonne CO2e
March 29
$15.10
22
21
20
19
18
17
16
15
14
13
12
2012
2013
2014
2015
2016
2017
2018

EU-ETS



European carbon credits price
Euros per tonne
Financial crisis leads to huge surplus of carbon credits due to reduced emissions
Price rises above €20 for first time since 2008
Market Stability Reserve, which begins in 2019, comes into focus
Decade-long slump deepens as excessive credits mount
25
20
15
10
5
0
2008
09
10
11
12
13
14
15
16
17
18
Source: Thomson Reuters
© FT

AB32



RMB / ton CO_2
Shenzhen
Shanghai
Beijing
Guangdong
Hubei
140
120
100
80
60
40
20
0
2013/6…
2013/1…
2014/5/4
2014/1…
2015/3…
2015/8…
2016/2/3
2016/7…
2016/1…
2017/5…

Comparison of standards, taxes, permits

What do we know so far

So far we have seen that:

1. Standards, taxes, and tradable permits can all achieve the efficient allocation
2. Taxes and tradable permits are cost-effective **no matter what**
    - (all firms set MAC = τ and MAC = p)

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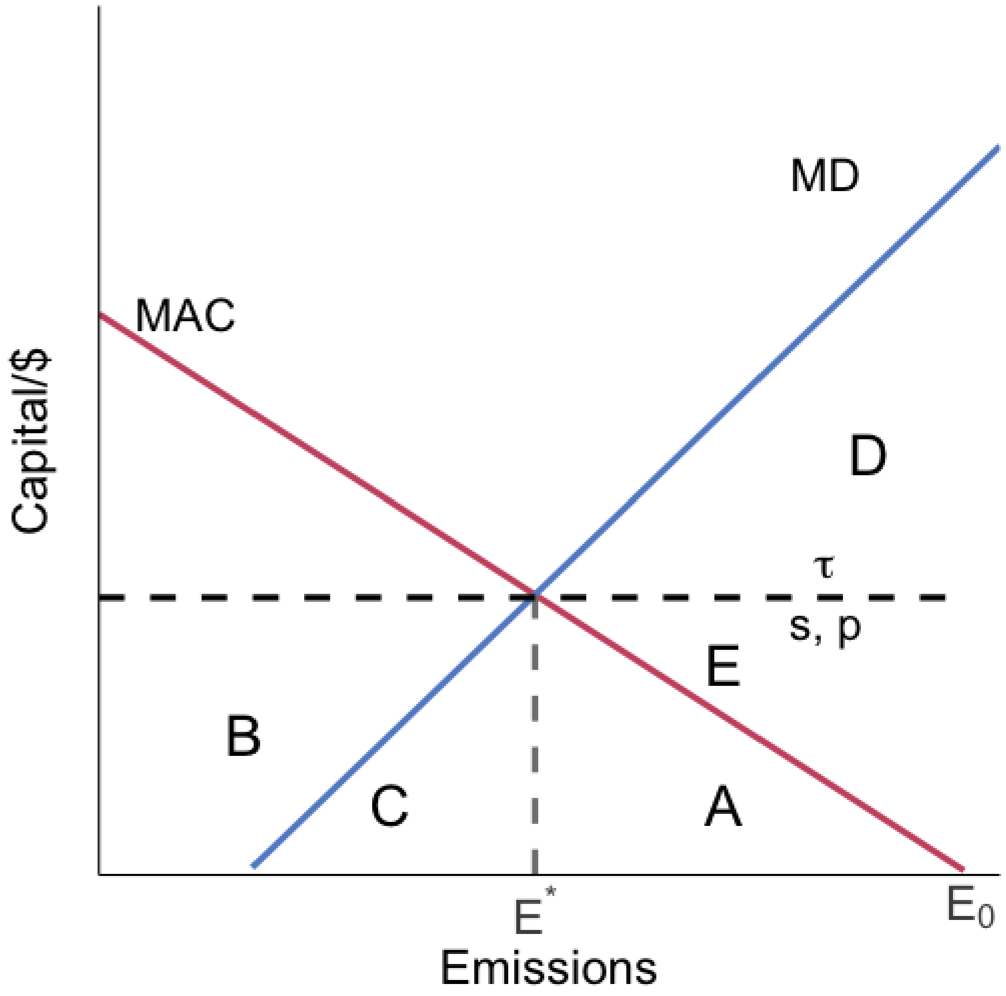
So far we have seen that:

1. Standards, taxes, and tradable permits can all achieve the efficient allocation
2. Taxes and tradable permits are cost-effective **no matter what**
    - (all firms set MAC = τ and MAC = p)

This still leaves a few questions to answer:

1. What are the equity effects?
2. What are the output effects?
3. What are the administrative burdens?
4. What are the **dynamic** incentives under these policies?

The equity set up

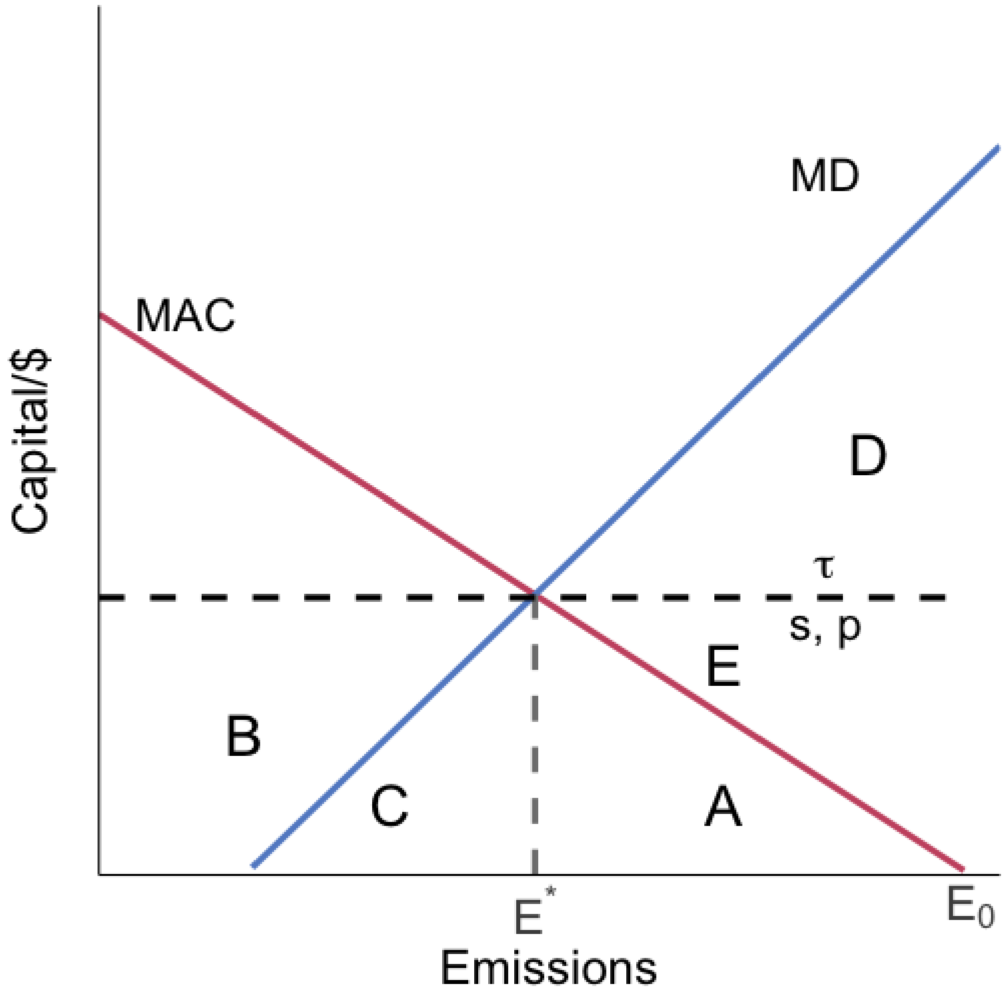


Lets consider this our base set up for 1 firm

The regulator can achieve E^* through:

- an emission standard of E^*
- a tax of τ
- an abatement subsidy of s
- "tradable permit" cap of E^*

The equity set up

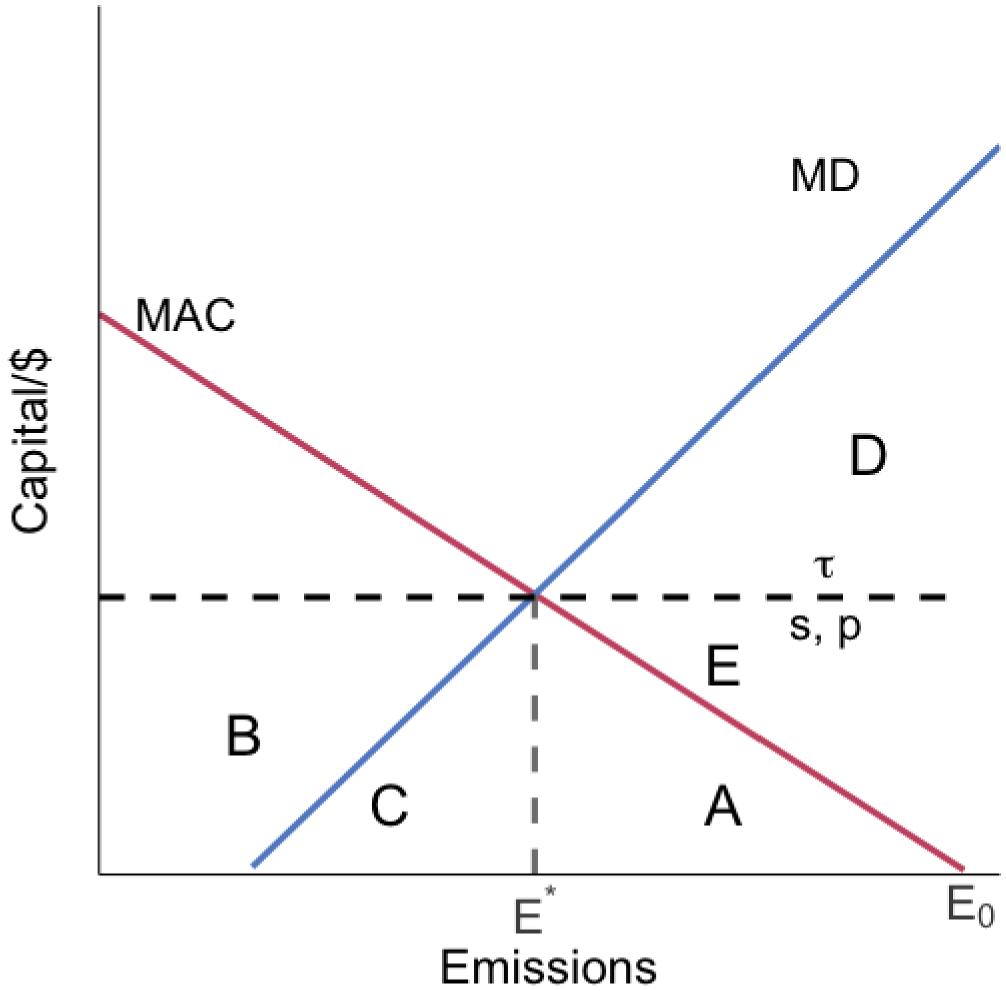


First let's look at **equity**

How do the costs and benefits of the policies fall on different groups?

From here on we will roll the tax and permit system into 1: they are actually identical in terms of their impacts

The distributional outcomes



	Tax/Permits	Standard	Subsidy	Ranking
Firm	-(A+B+C)	-A	E	Sub > Std > Tax
Households	A+D+E	A+D+E	A+D+E	Indifferent
Government	B+C	0	-(E+A)	Tax > Std > Sub
Total	D+E	D+E	D+E	

The total welfare gain is the same for all policies

The difference is in the **distribution**

The standard strikes a middle ground out of the three

Output effects

So far we have assumed that actual firm output is not affected by abatement/emission decisions

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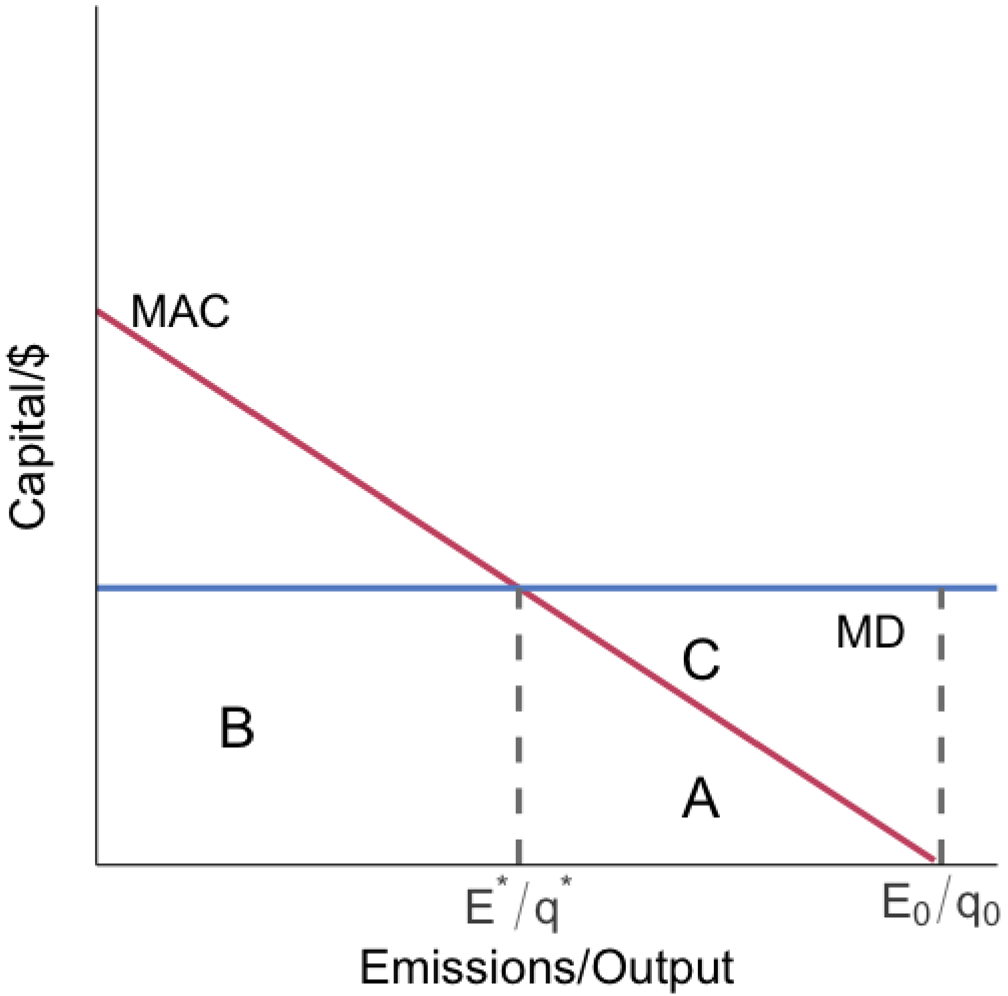
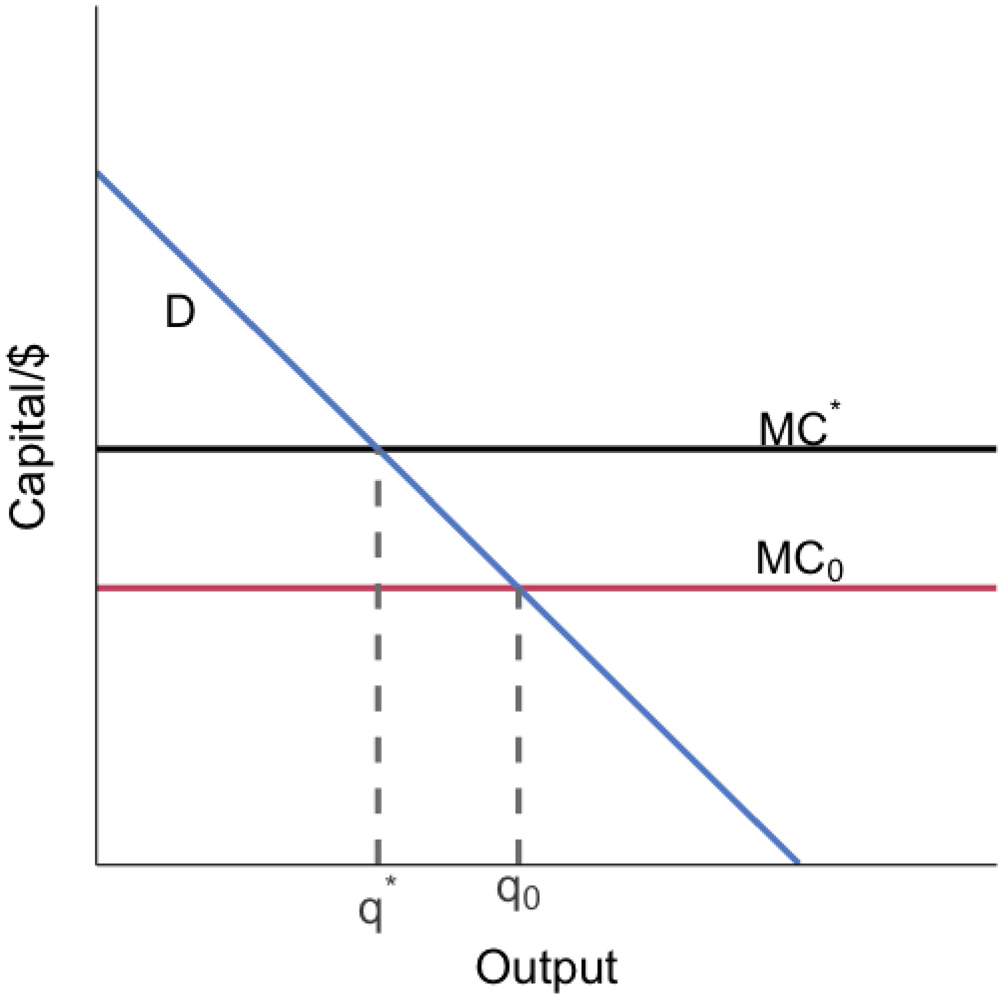
Different policies have different implications for total cost and can thus affect production

To keep things simple lets suppose the firm has constant returns to scale technology and chooses the emissions rate / emissions per unit of output: E/q, this means that if they cut back on emissions it raises the MC of output

The output set up





The output results

Emission tax:

- Firm chooses E^*/q^*
- Firm pays A+B in tax and abatement cost **per unit of output**
- This raises the MC of production by A+B to MC*
- Output q^* falls
- Pollution $(E^*/q^*) * q^*$ falls even more since the tax lowers the optimal E^*/q^*, and increased MC lowers q^*

The output results

Emission standard:

- Firm pays A in abatement cost per unit of output
- This raises the MC of production by A
- Output and $(E^*/q^*) * q^*$ fall, but not by as much as under the tax

The output results

Abatement subsidy:

- Reduces firm costs per unit of output by C
- This reduces the MC of production by C
- This **raises** output
- Even though E/q goes down because the subsidy induces a lower emission intensity, total emissions may go up because q will rise

The output results

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- Reduces firm costs per unit of output by C
- This reduces the MC of production by C
- This **raises** output
- Even though E/q goes down because the subsidy induces a lower emission intensity, total emissions may go up because q will rise

- Output falls under taxes and standards
- This raises output prices
- Can have regressive effects through necessities like electricity or gas

Administration

These policies are not equivalent in their cost of implementation

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Enforcing a technology standard is very easy: you can inspect to see if they have installed the tech or not

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Firms have incentives to try to cheat!

Administration

Pigouvian policies will not work as well for **non-point sources** like cars or farms

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Point sources like power plants are much easier to handle with Pigouvian policies like taxes

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This might make things more politically difficult to pass

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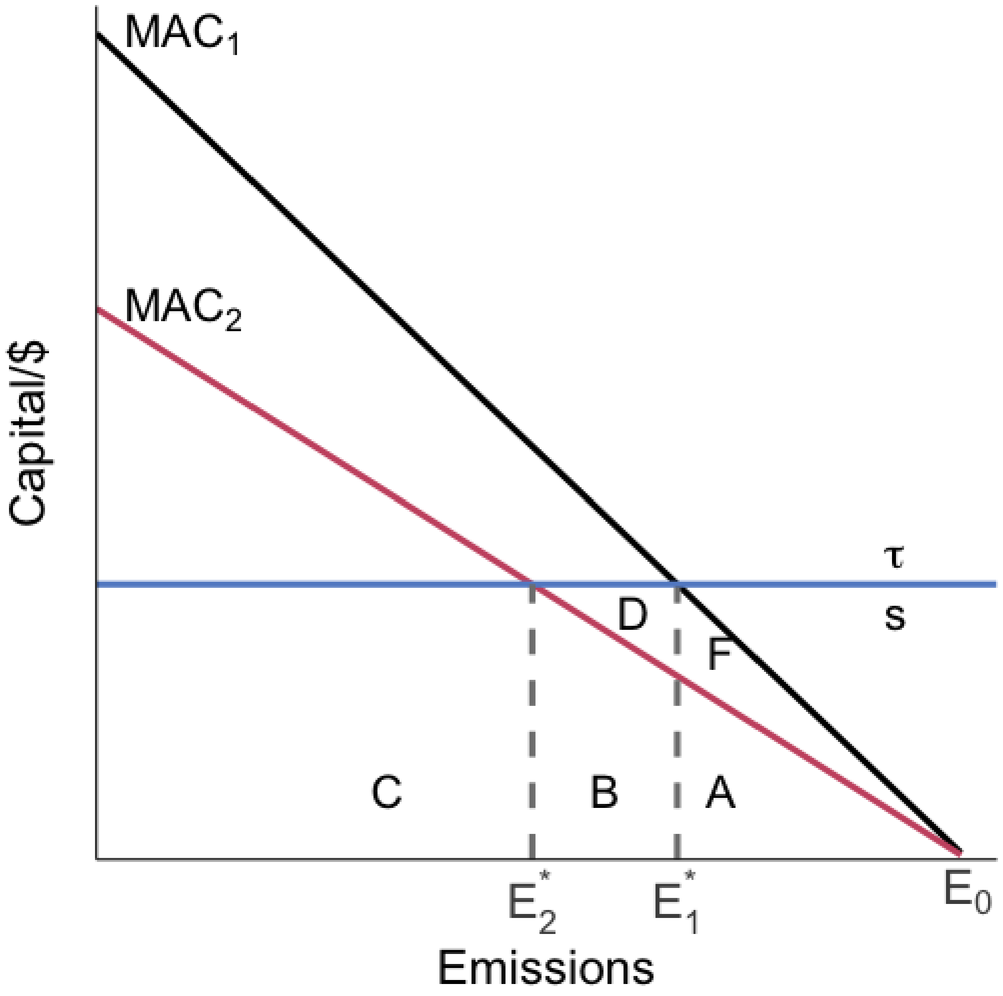
When does C&C / technology standards make sense?

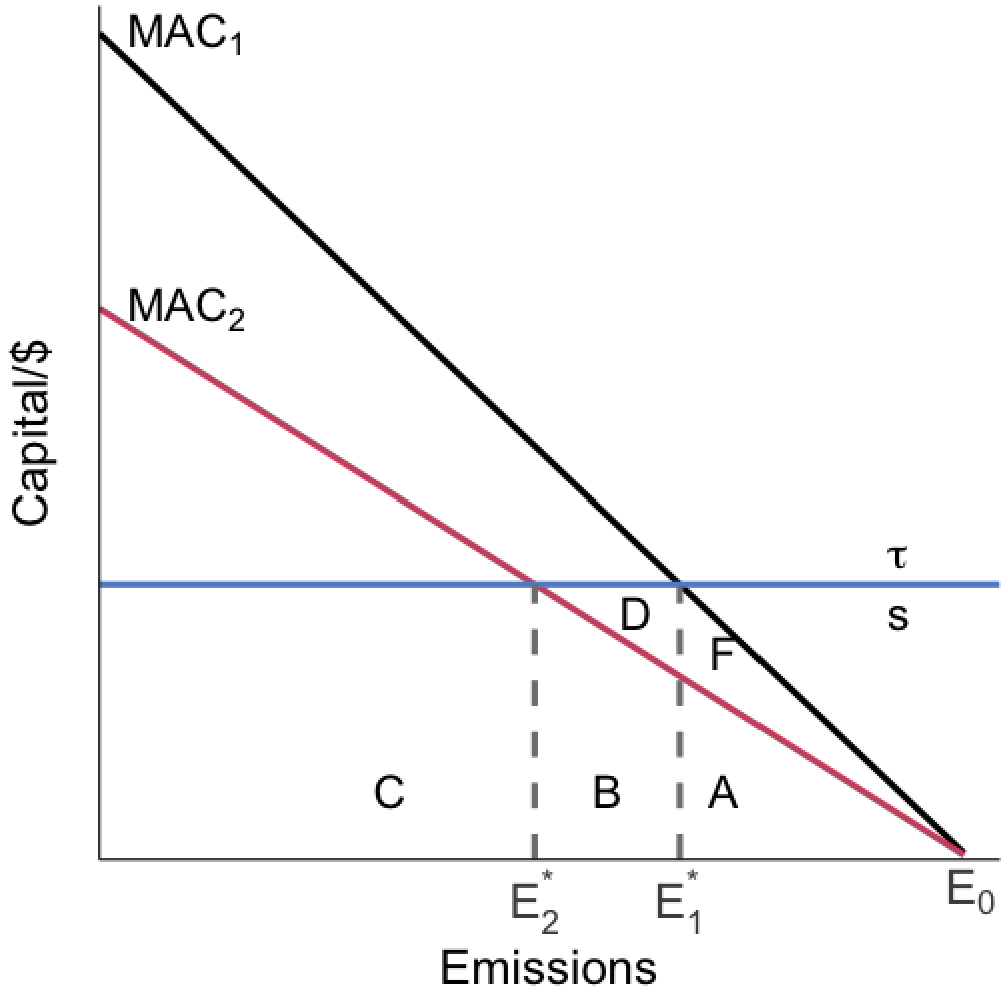
1. If there's a dominant technology where there's benefits to coordination or scale economies from production of the technology
2. High costs of monitoring/enforcement
3. High admin costs and little heterogeneity across firms

Dynamic incentives



What are the gains to the firm from moving from MAC_1 to MAC_2?

Dynamic incentives



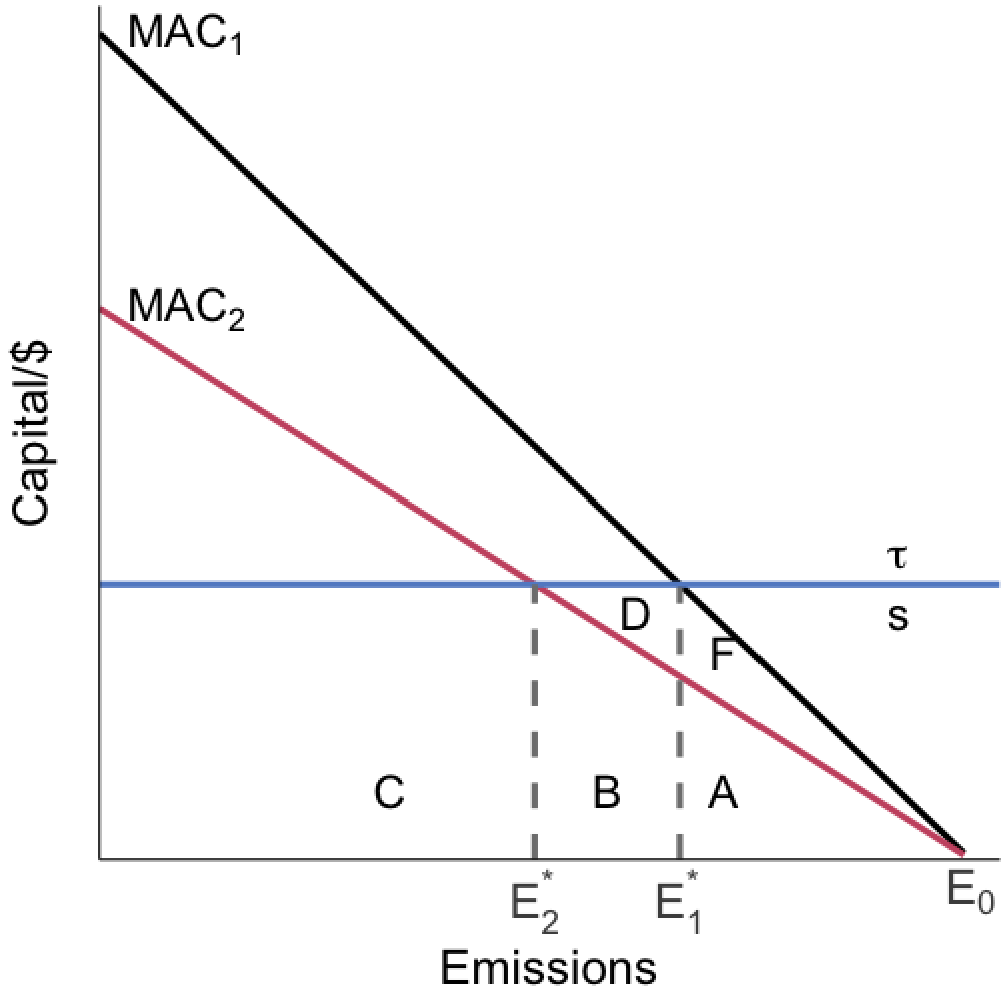
What are the gains to the firm from moving from MAC_1 to MAC_2?

Standard: F (abatement cost reduction)

Emission Tax: F + D (abatement cost and tax payment reduction)

Abatement Subsidy: F + D (abatement cost reduction and abatement subsidy increase)

Dynamic incentives



What are the gains to the firm from moving to MAC_2?

Taxes and subsidies give greater incentives to innovate!

Once a firm meets a standard, there's no additional incentive beyond reducing abatement costs

Taxes and subsidies give the firm extra benefits for further reductions