Interdisciplinary Summer School VIENNA

Externalities, pigovian taxes & ETS

SAV21-Sustainable Energy

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  - UJEP

Economics of pollution

1. Refresh free market economics basics
2. Introduce carbon emissions as an externality
3. Introduce 2 possible solutions
    1. Carbon Tax
    2. *Emission Trading Scheme (ETS)*
4. Overview carbon taxation & ETS in the world
5. How well is EU ETS doing?

Economics of pollution

1. Refresh free market economics basics

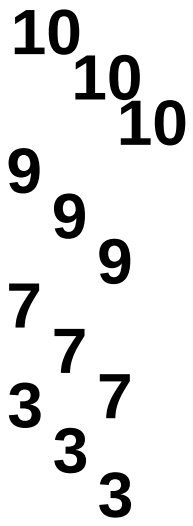
Any idea how many goods will be sold?

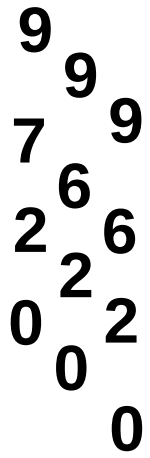
- Consumer:
- Maximum buying price

And at what price?

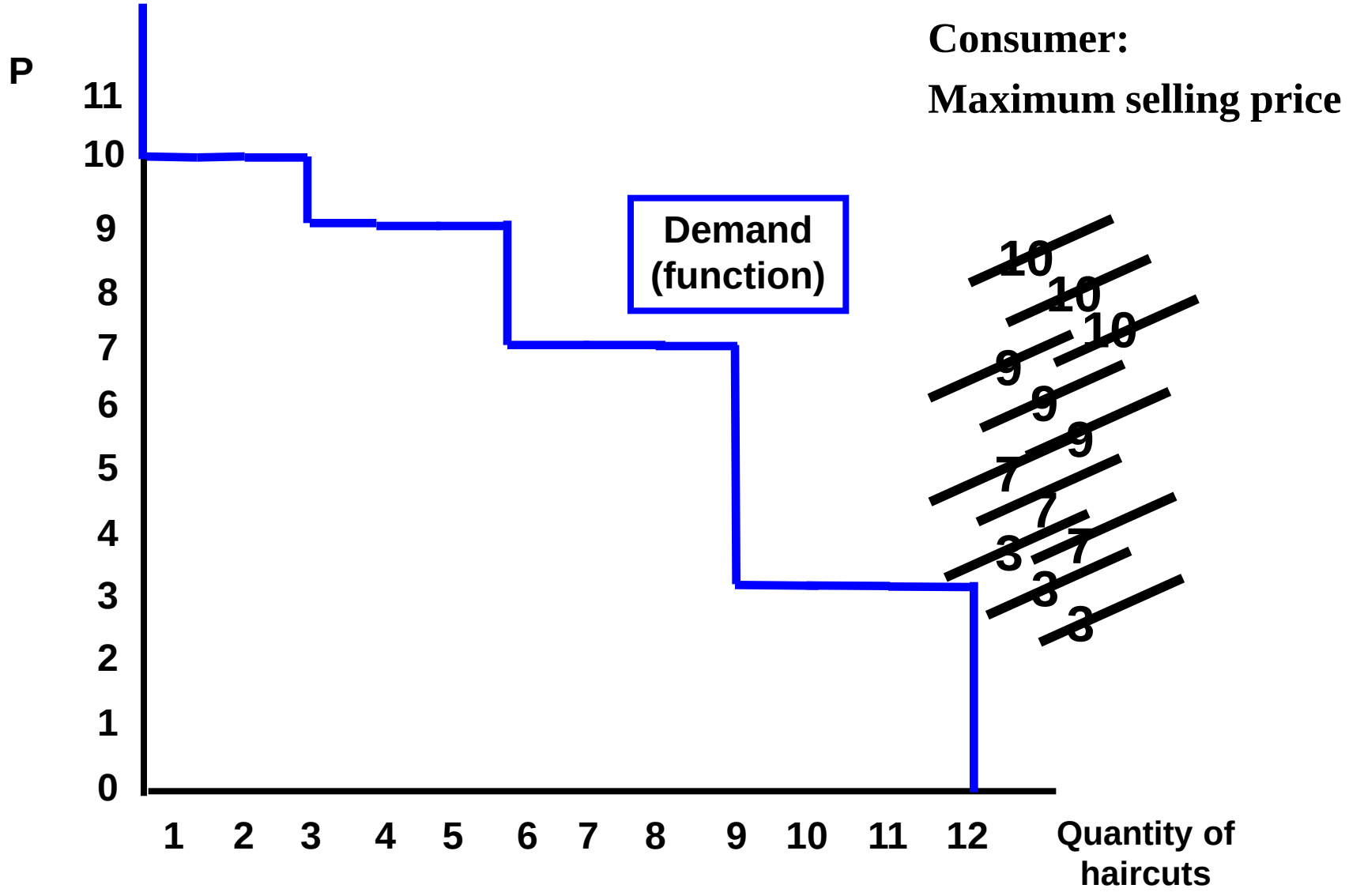
Producer:

Minimal selling price





Deriving a the equilibrium price



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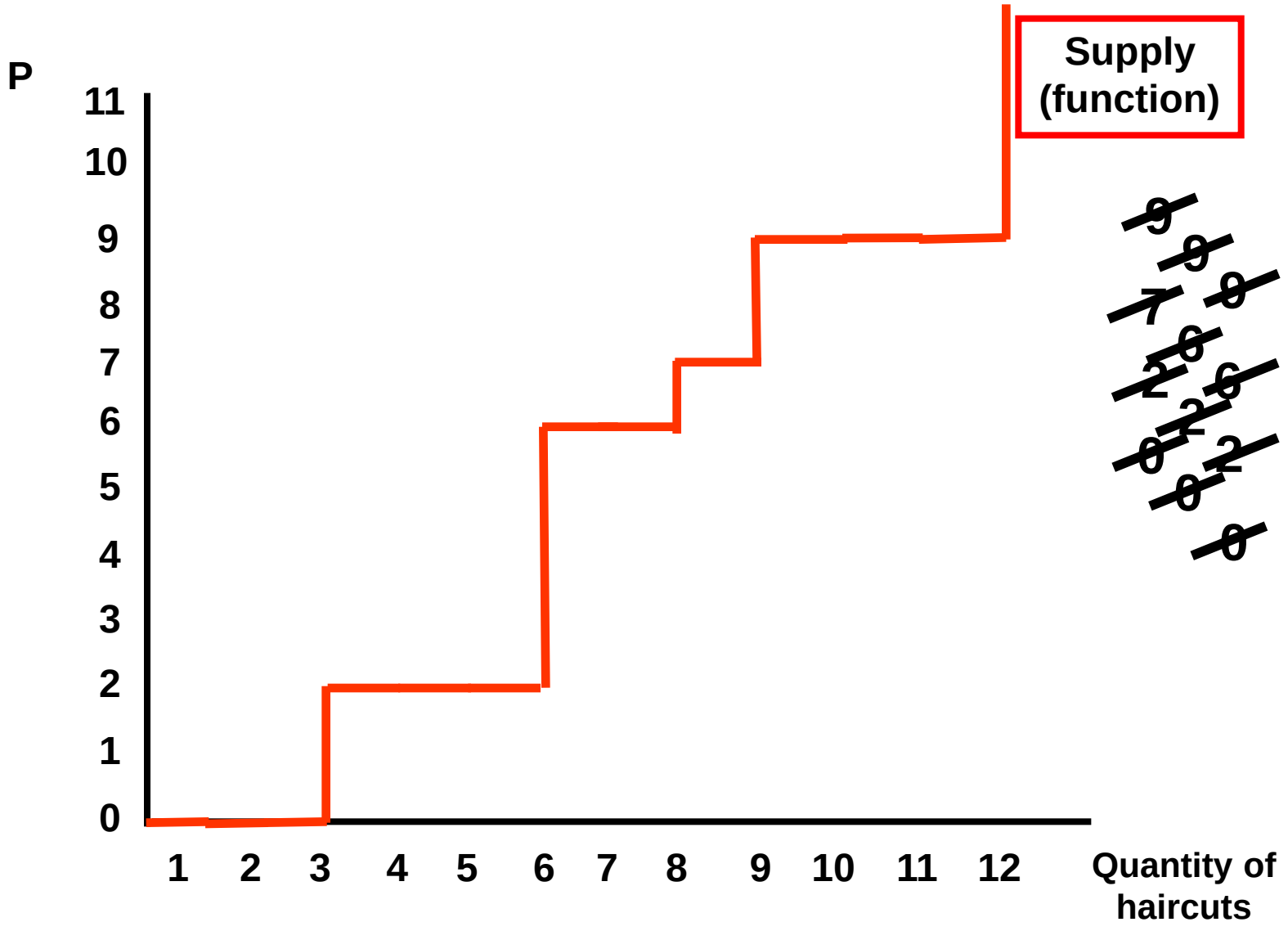

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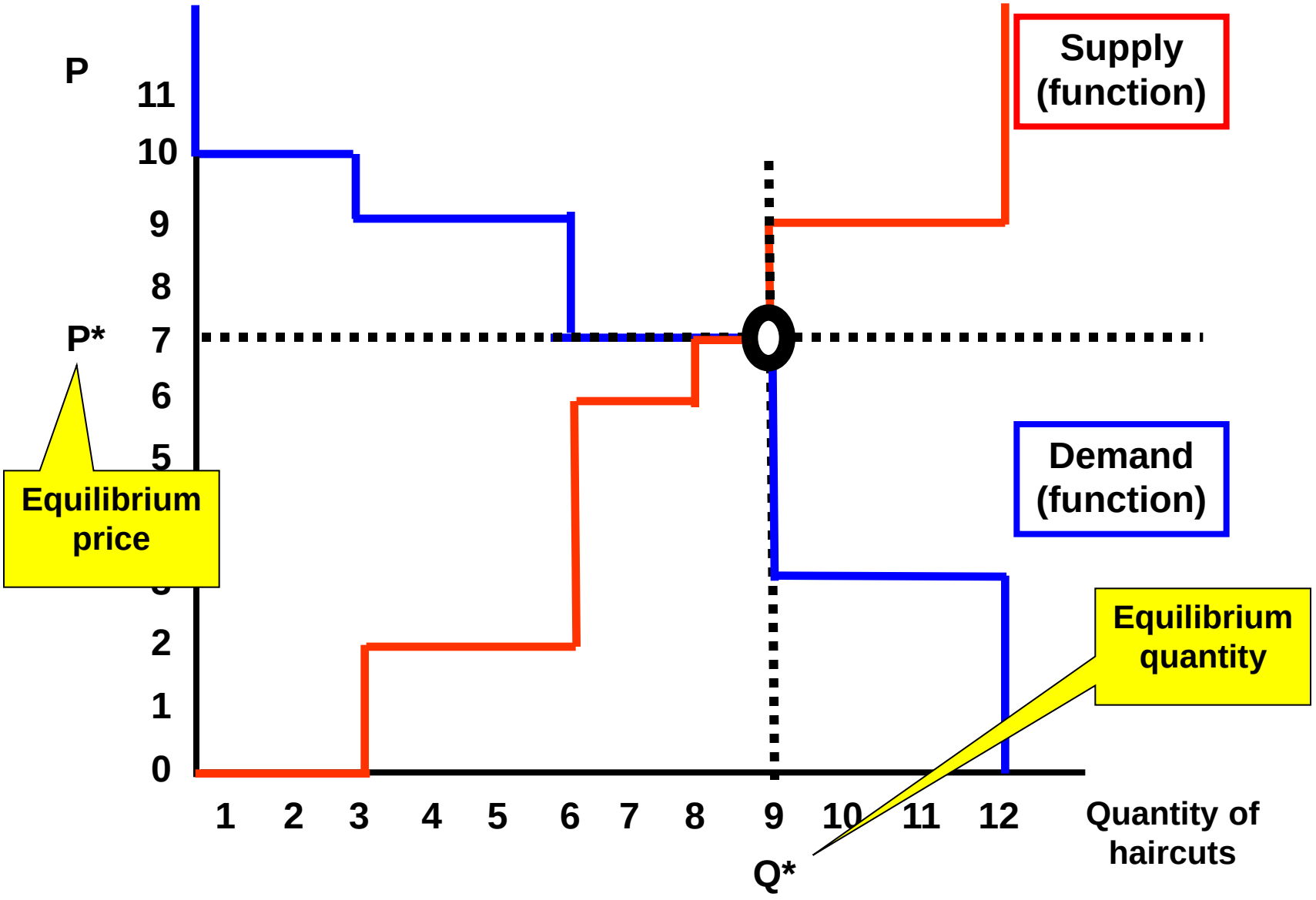
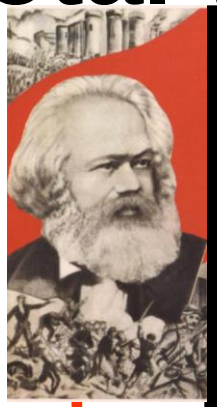


Looking at total welfare



You do matching!

- Always pair the strongest buyer with the strongest seller.
- Until supply and demand intersect
- Isn't that unfair?
- Weakest guys are pushed from the market!

PS=38

=15

W= 53

P

P*

Equilibrium price

(function)

Equilibrium quantity

Quantity of haircuts

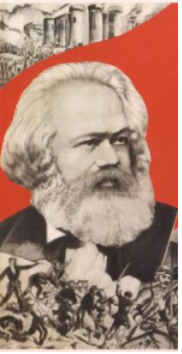
Q*

11 10 9 8 7 6 5 2 1 0

1 2 3 4 5 6 7 8 9 10 11 12

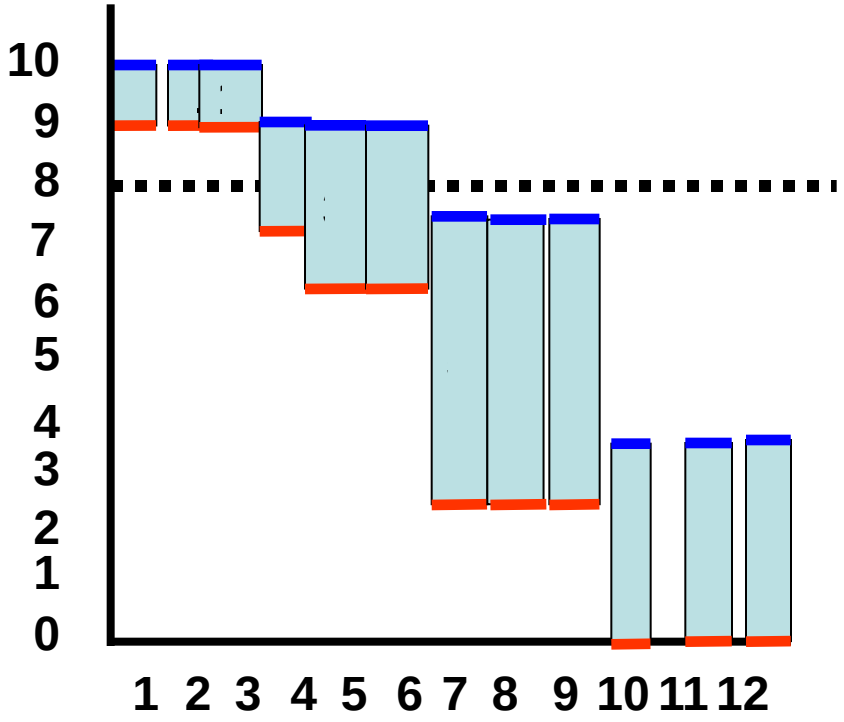
3 3 3 2 2 2 1 1

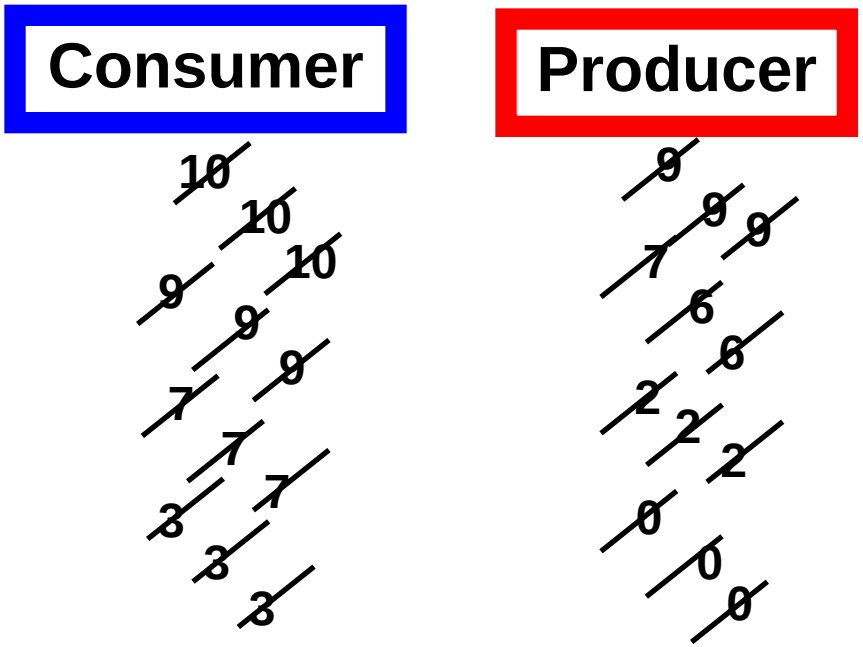
7 7 7 5 5 5



Other possible arrangements: Communist *"fair"* dictator

Could this be more efficient?

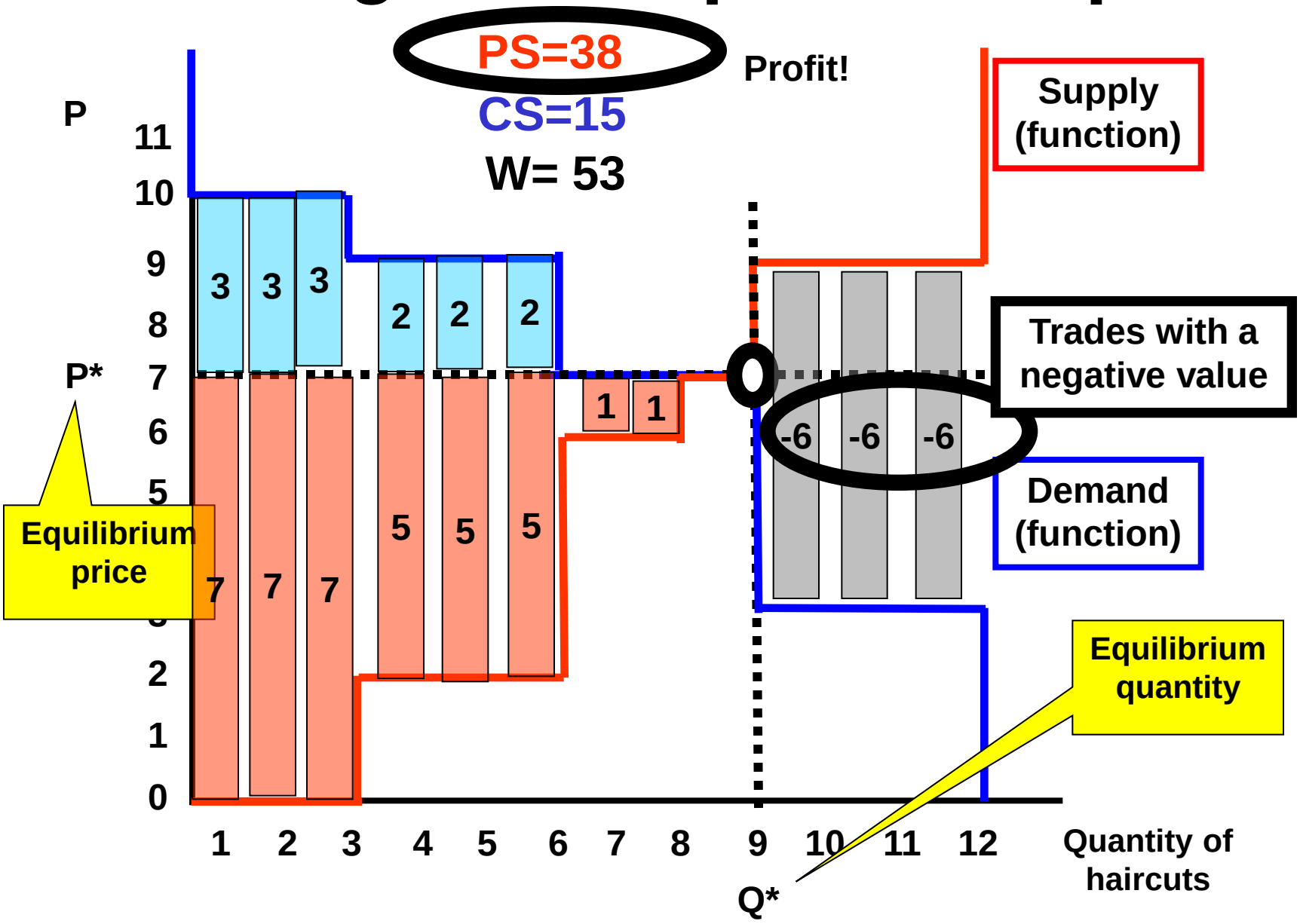




W= 35
W(Free market)=53
(difference =18)

Free market maximizes W=CS+PS

Deriving a the equilibrium price



- There is an optimum: the max welfare (52)
- There are different mechanisms to try to reach or approach this mechanism

2. Form of central planning
   - Easy to do suboptimal
   - Usually not self-enforcing (incentive-compatible)
1. Free market
   - Maximum welfare
   - Self-enforcing (ic)
   - But, only true when no **externalities**.

- Global warming is an externality problem

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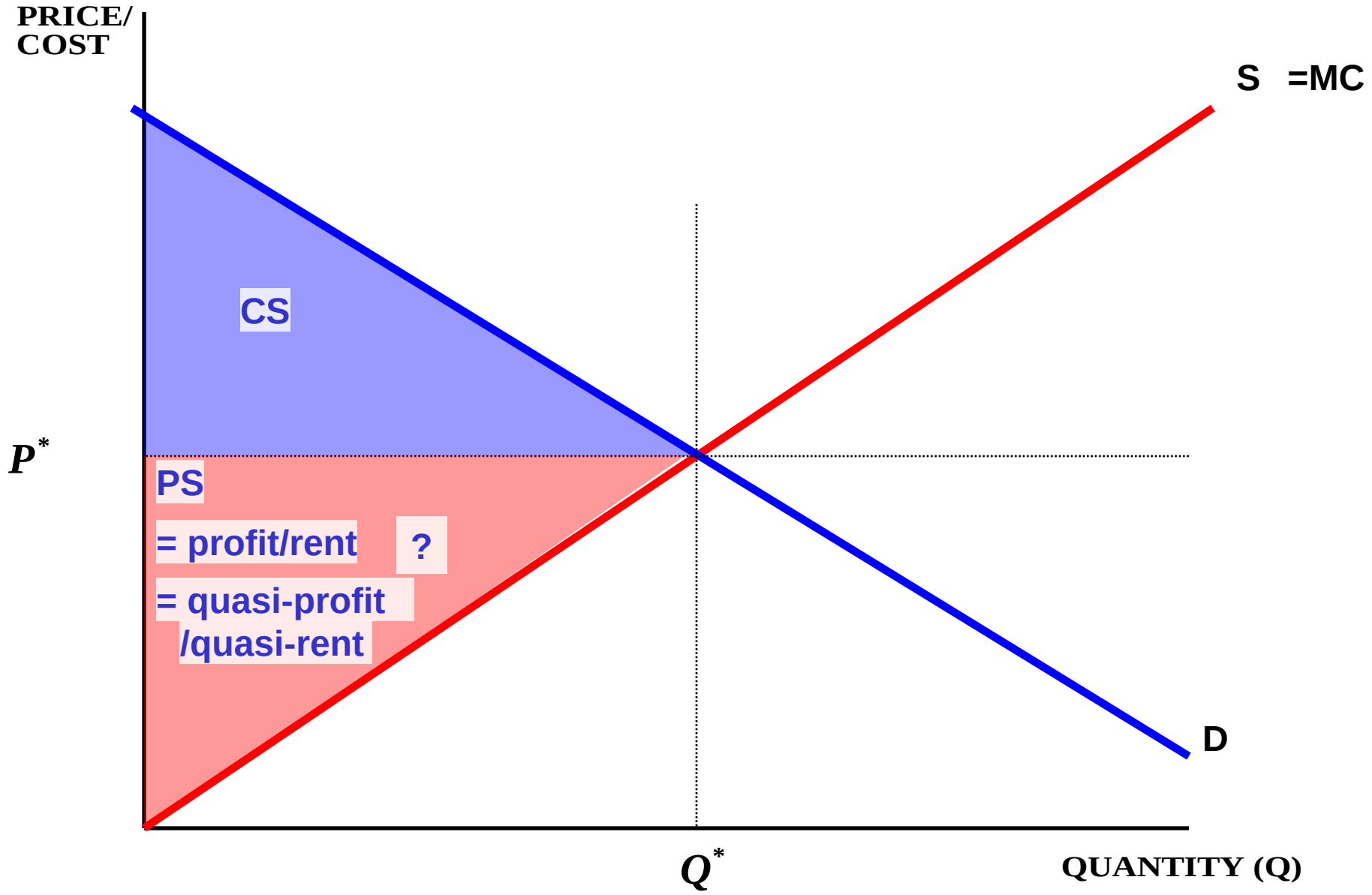
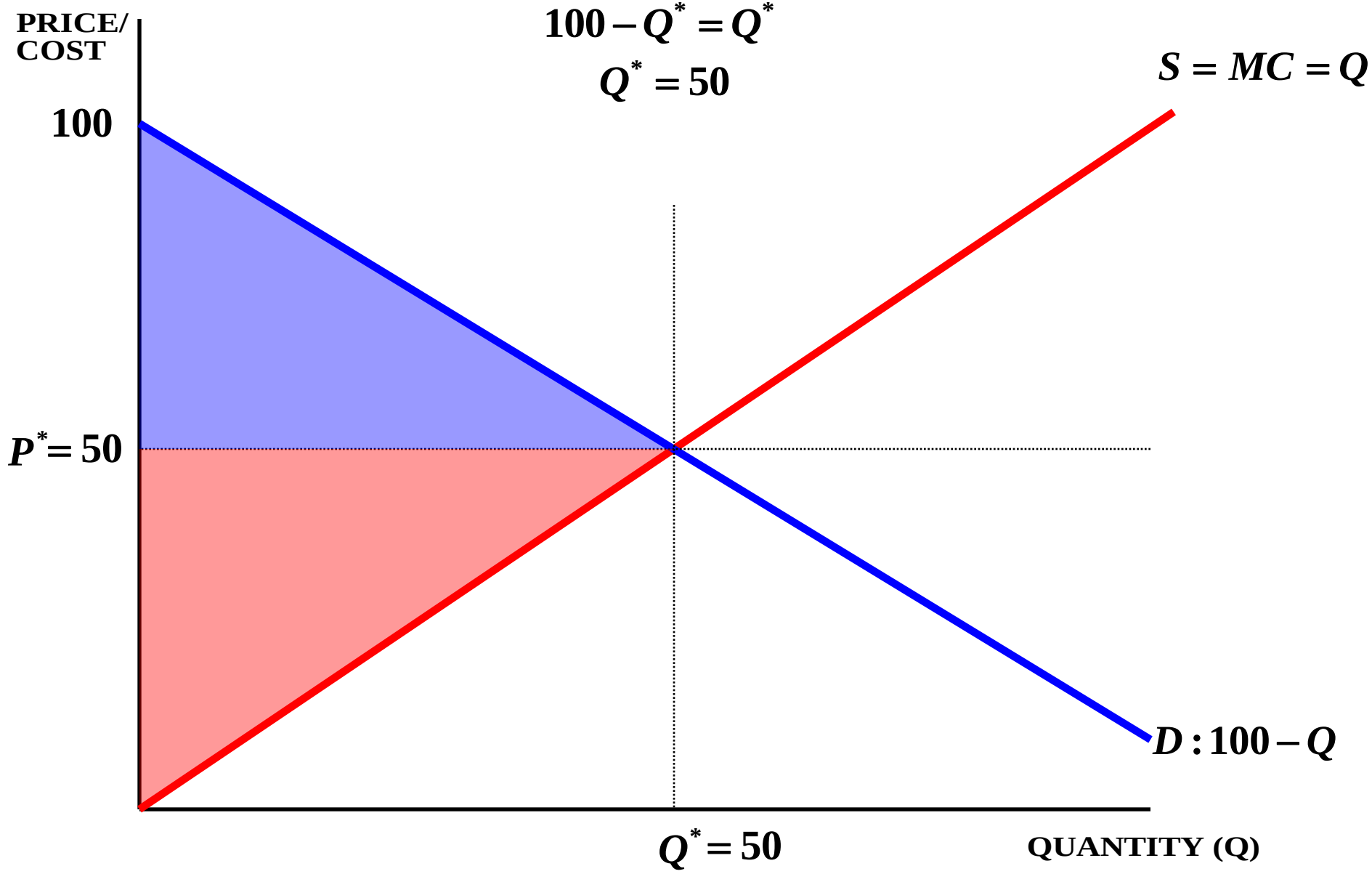

PRICE/
COST
S =MC
CS
P*
PS
= profit/rent
?
= quasi-profit
/quasi-rent
D
Q*
QUANTITY (Q)

What is the numeric prediction?

$$D = S$$

$$100 - Q^* = Q^*$$

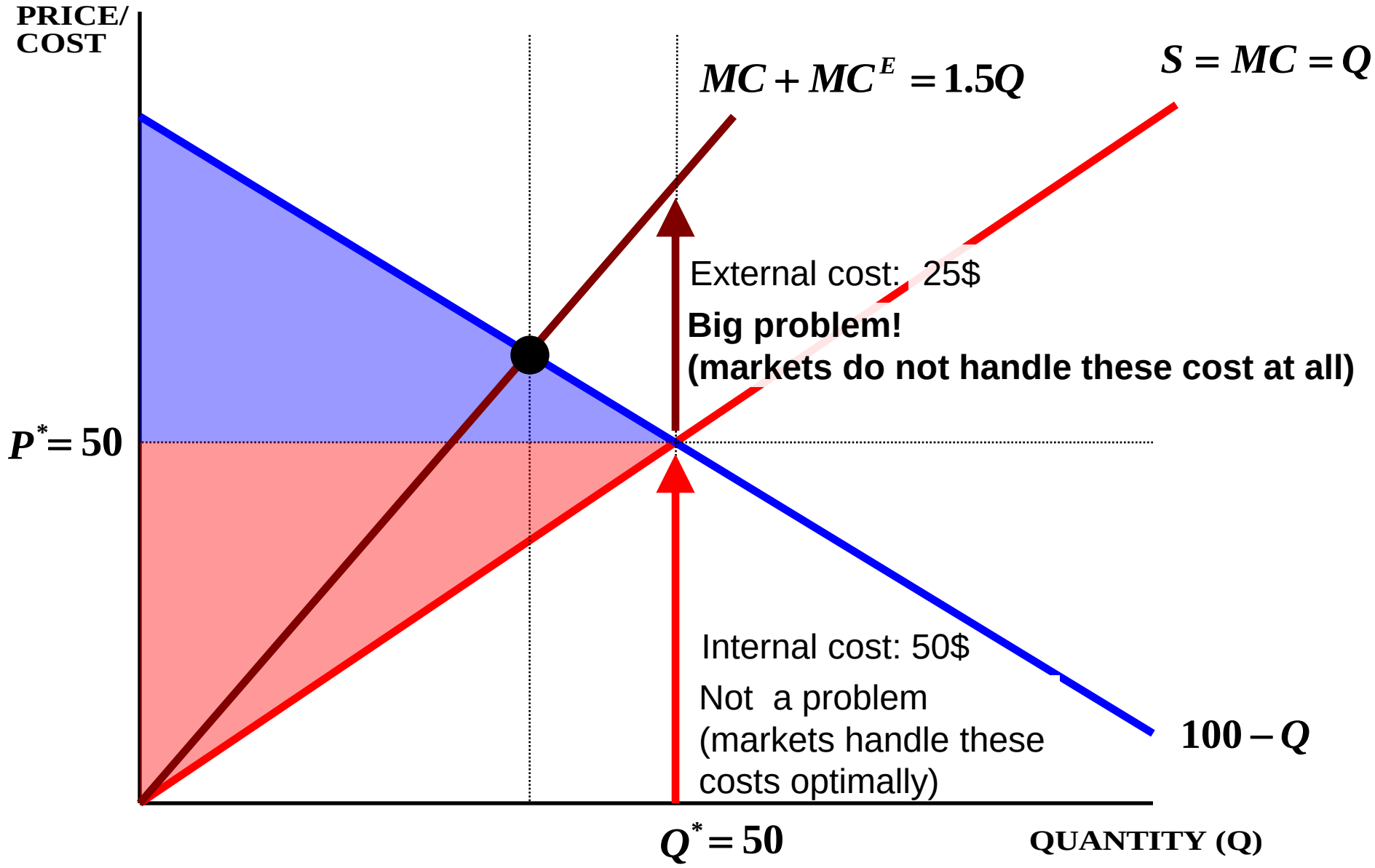
$$Q^* = 50$$



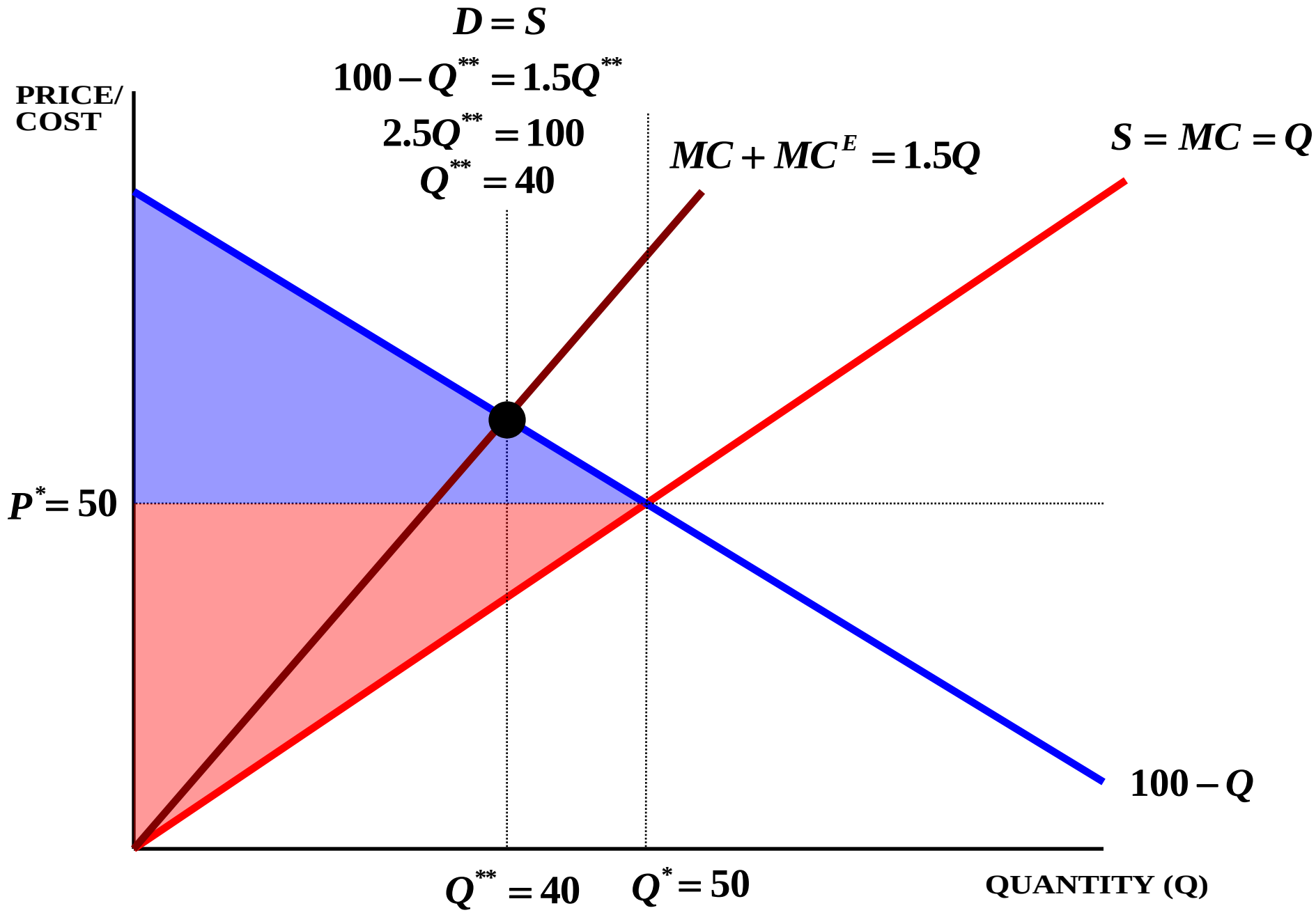
- We must look at the theory of **Externalities**
  - The price of a good does not reflect all of its costs
  - Markets are missing for these inputs

What is the externality?

Is Q* still the optimum? No.

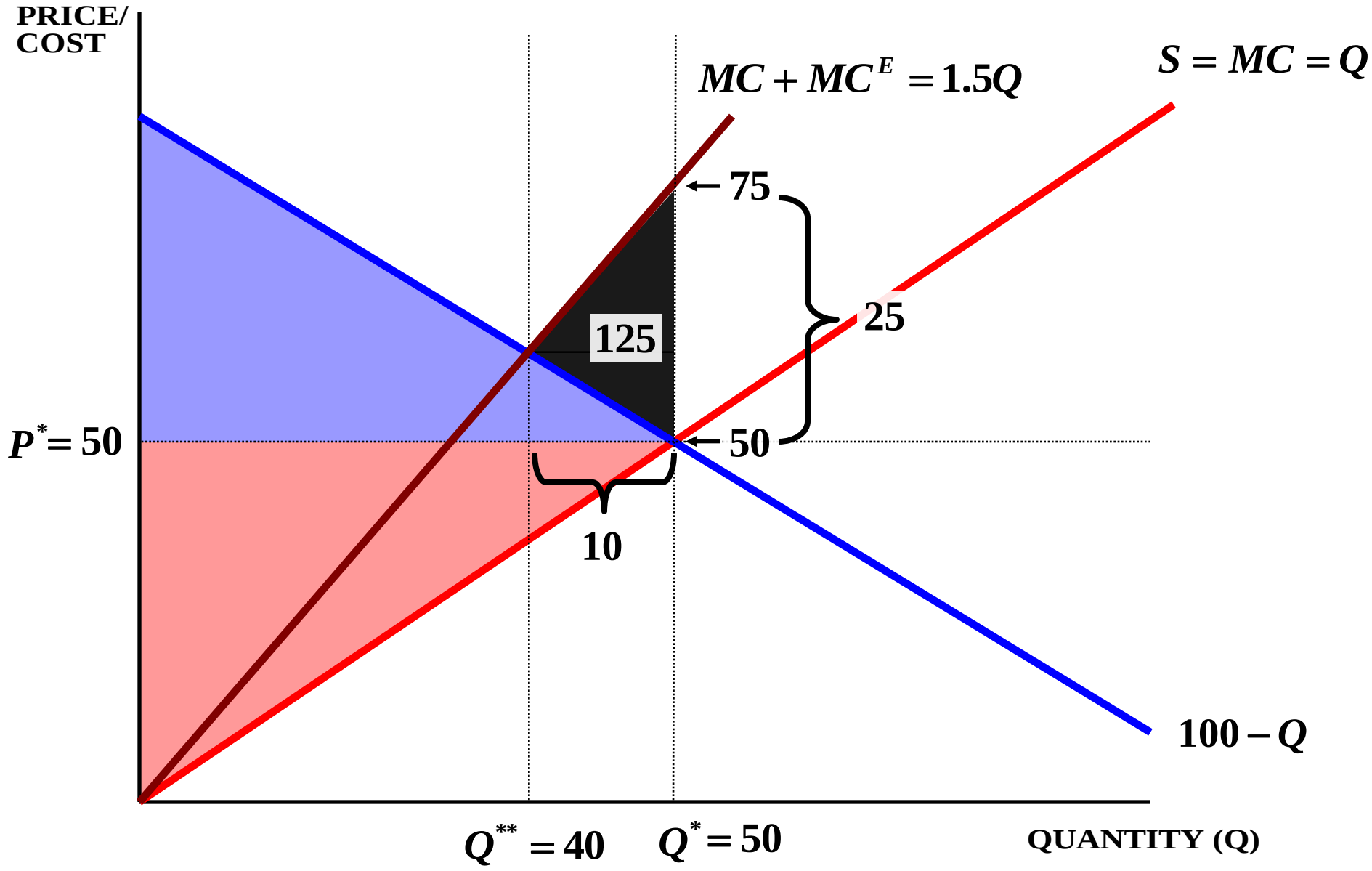


What is now the optimum?



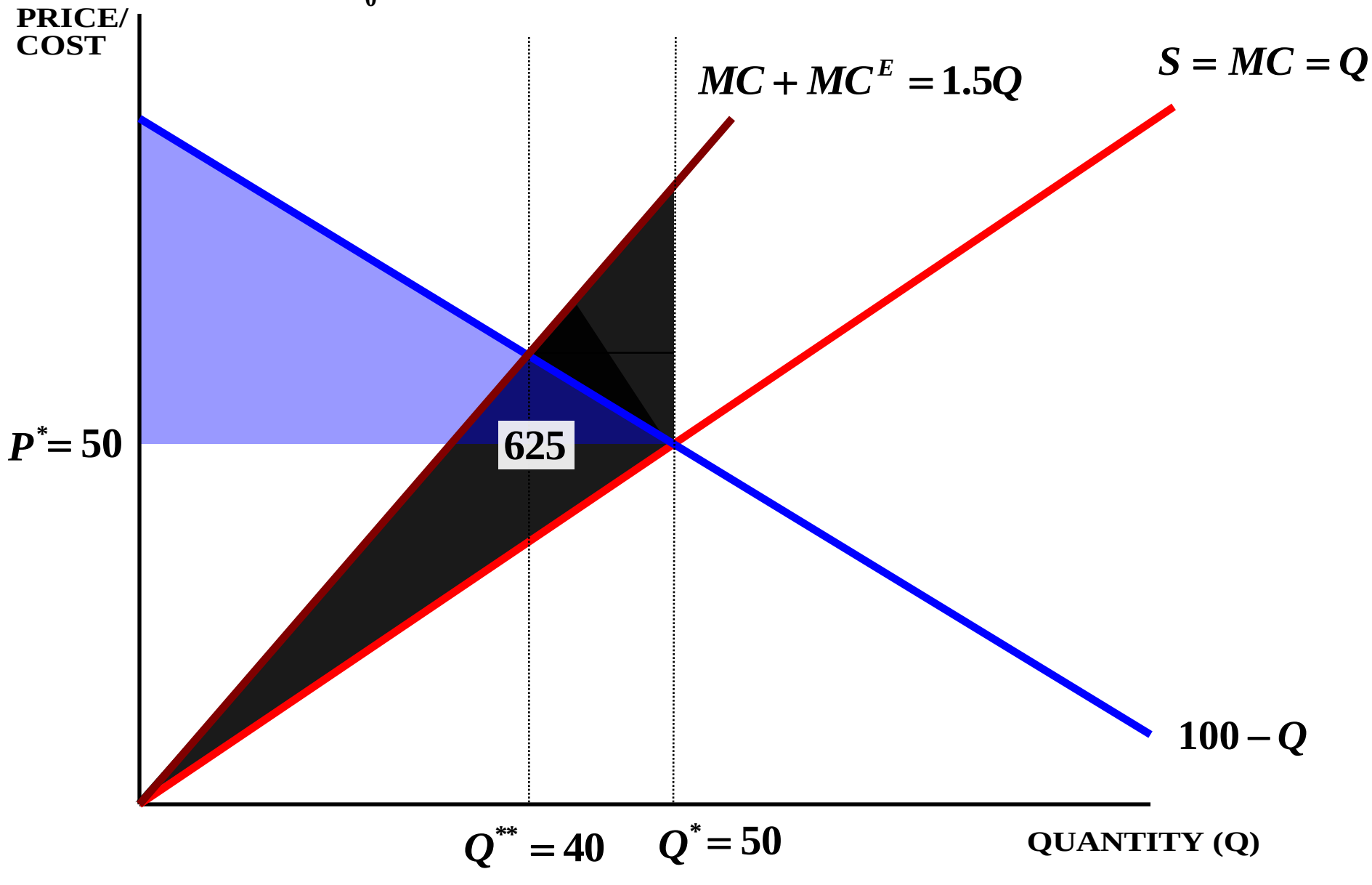
What is the damage to welfare of the externality?

$$\text{damage} = 25 \cdot 10 \cdot \tfrac{1}{2} = 125$$



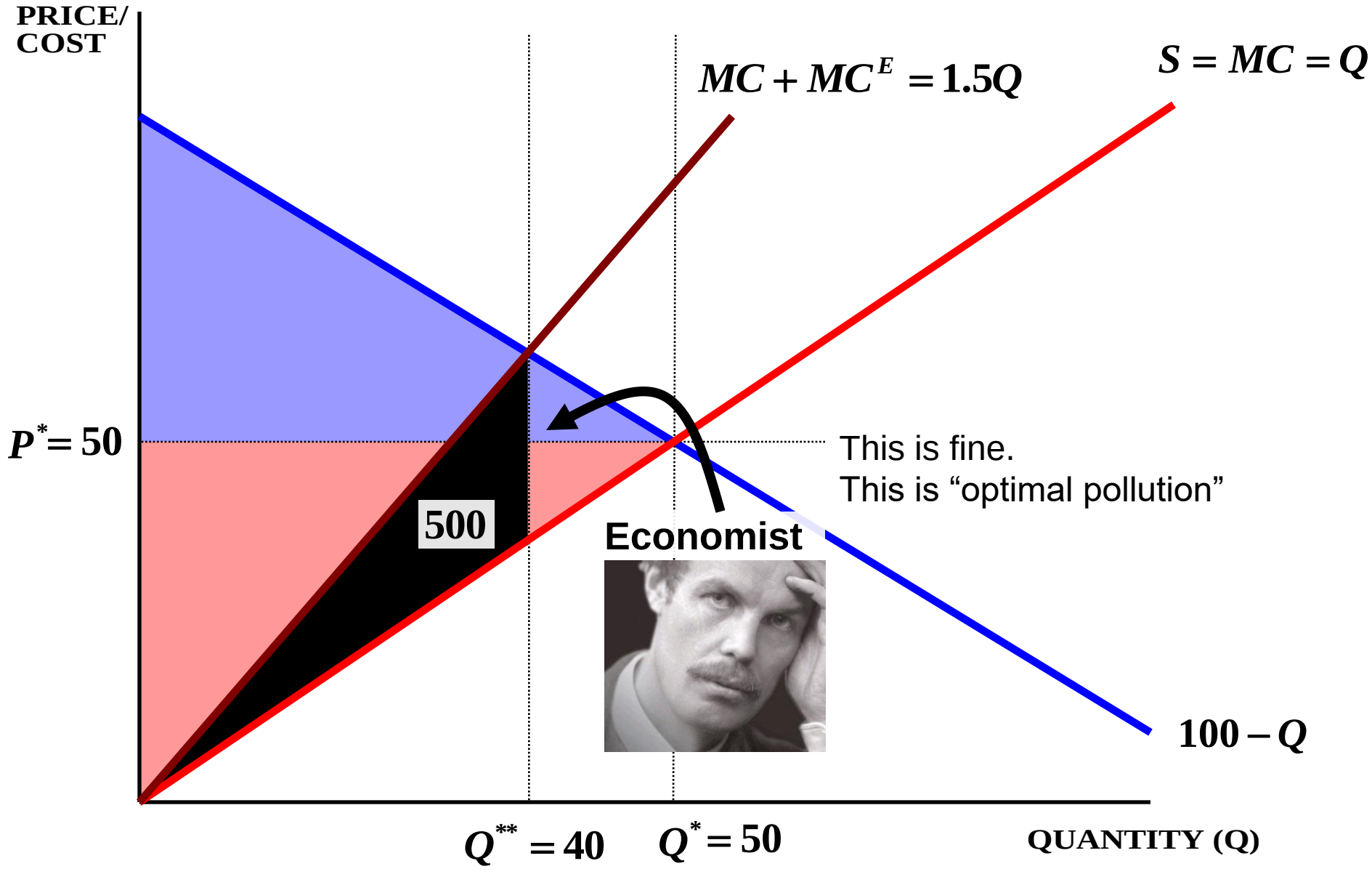
What is the total damage of the externality?

$$\text{damage} = \int_0^{50} (1.5q - q)dq = [.25q^2]_0^{50} = 2500/4 = 625$$



Why do (some) environmentalists hate economics?

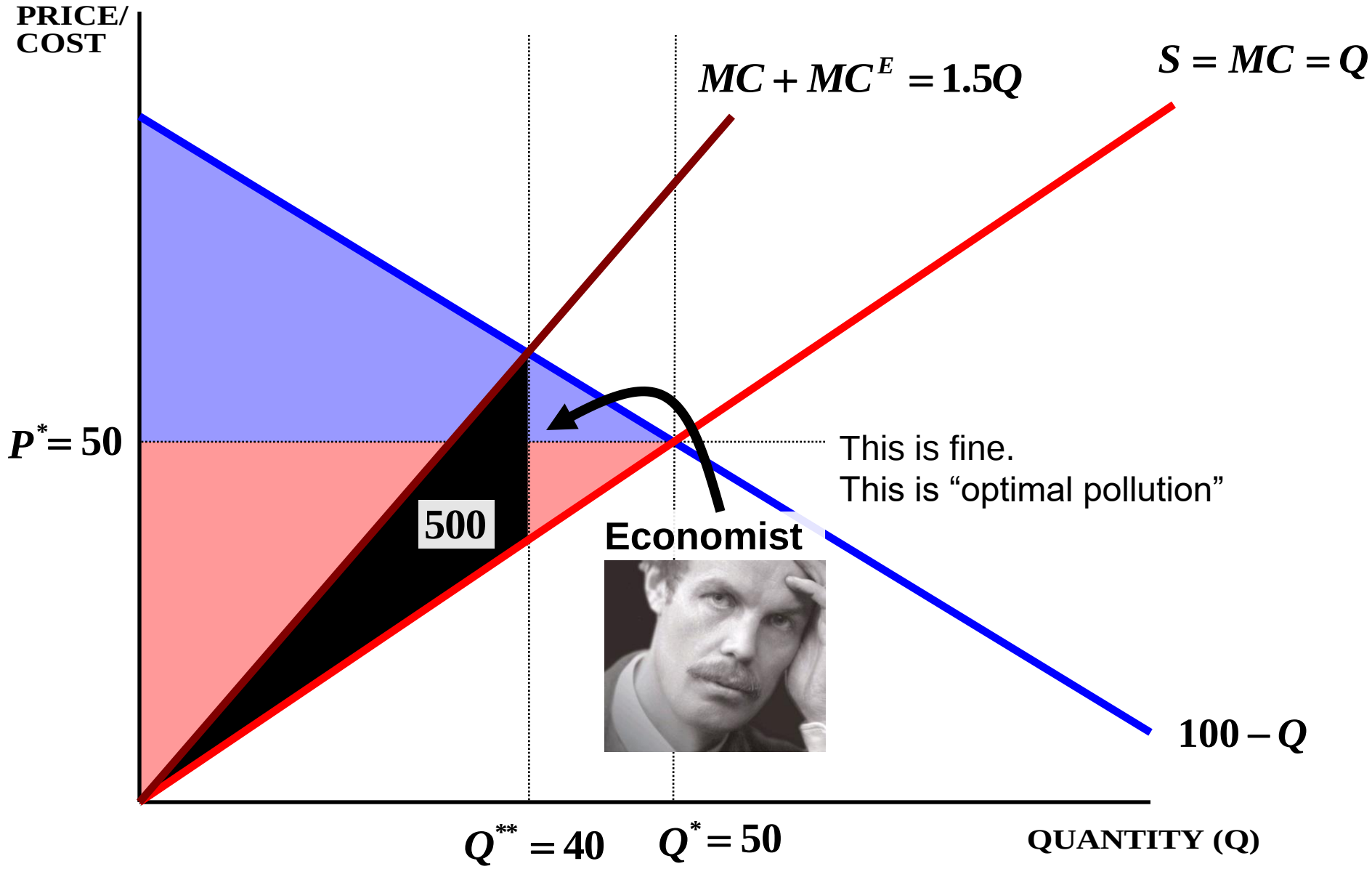
What is the optimal pollution?



Lettuce contains arsenic (a tiny bit)

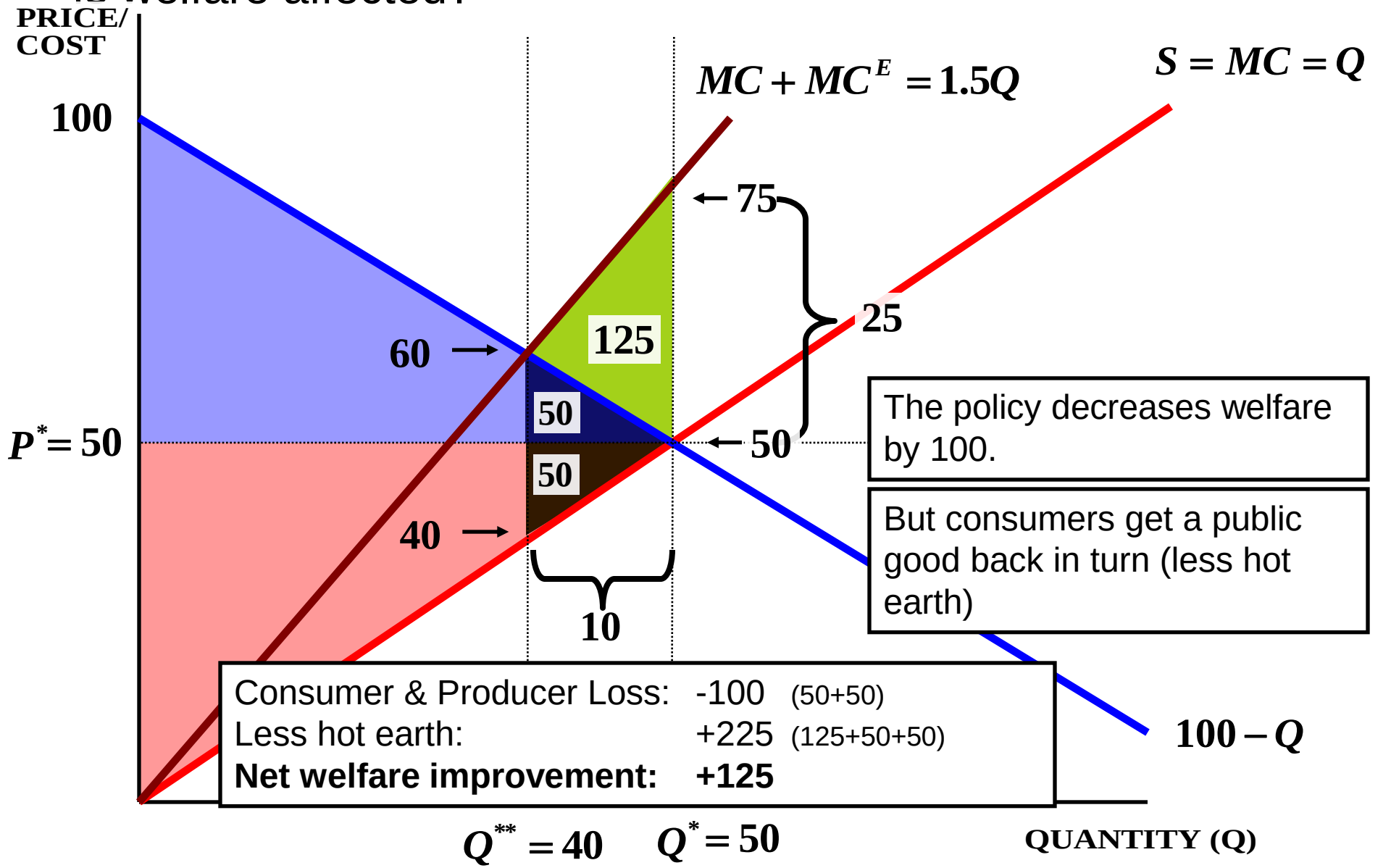
Why do (some) environmentalists hate economists?

What is the optimal pollution?



Assume we implemented a policy that moved us to the optimal outcome.

Is welfare affected?



The policy decreases welfare by 100.

But consumers get a public good back in turn (less hot earth)

Consumer & Producer Loss:	-100	(50+50)
Less hot earth:	+225	(125+50+50)
Net welfare improvement:	**+125**	

- We must look at the theory of **Externalities**
  - The price of a good does not reflect all of its costs
  - Markets are missing for these inputs

- What to do?
- Need regulation
- First-best regulation:
  1. Tax (Pigovian tax)
  2. Cap-and-trade (ETS)

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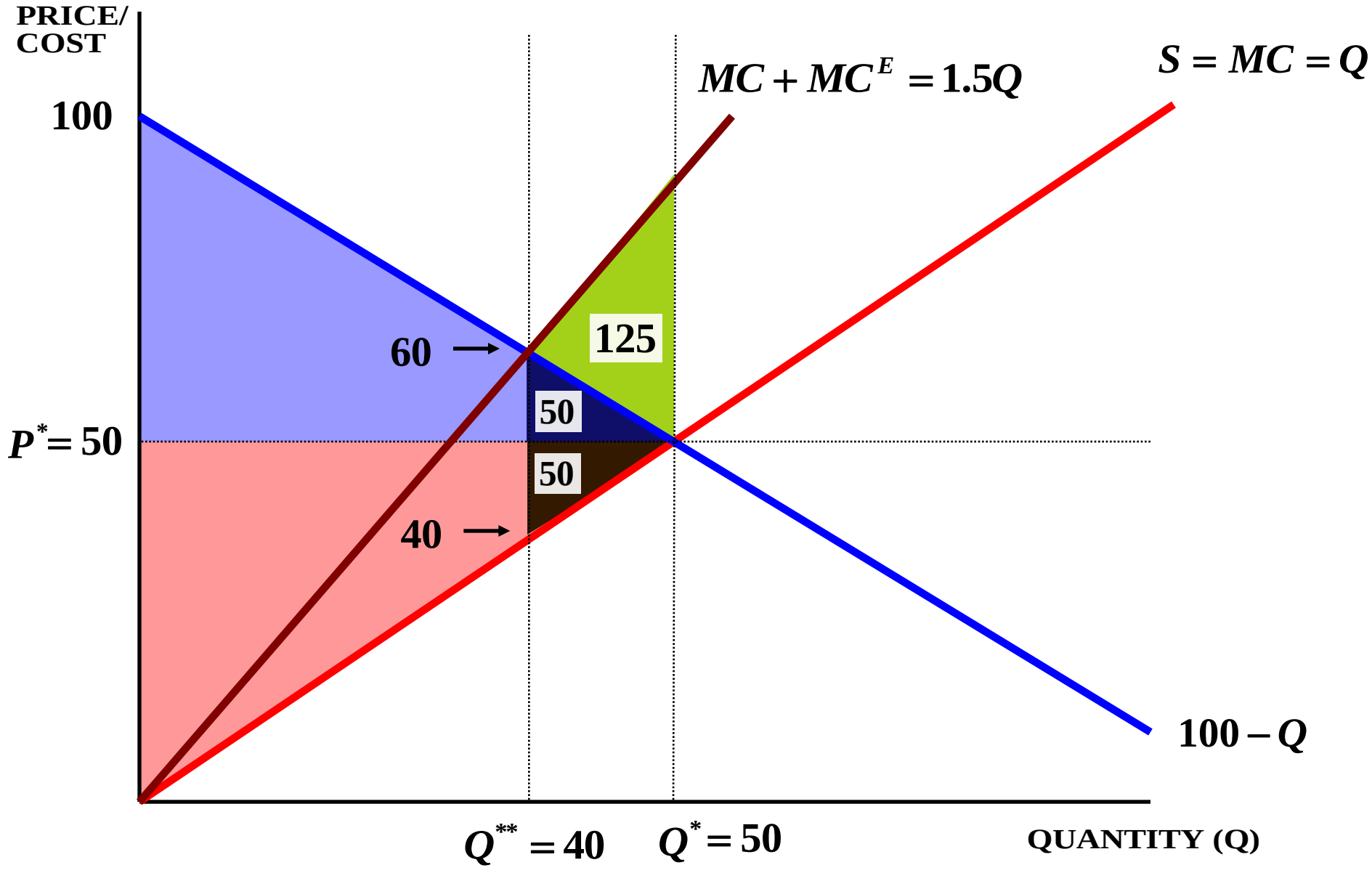
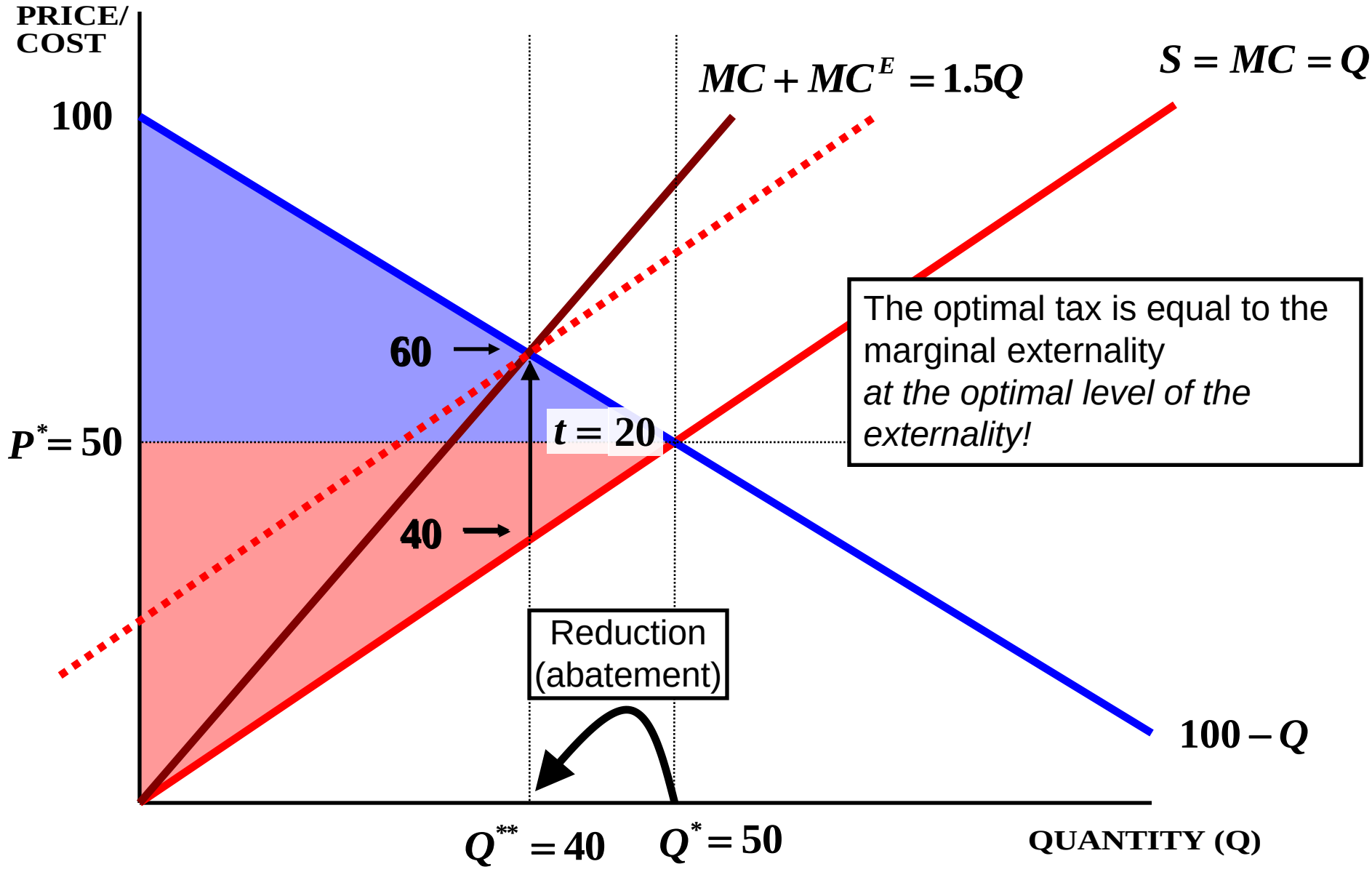
Carbon Taxing

3. Introduce carbon tax

How can we make the outcome optimal.



How can we use a tax to moved us to the optimal outcome?



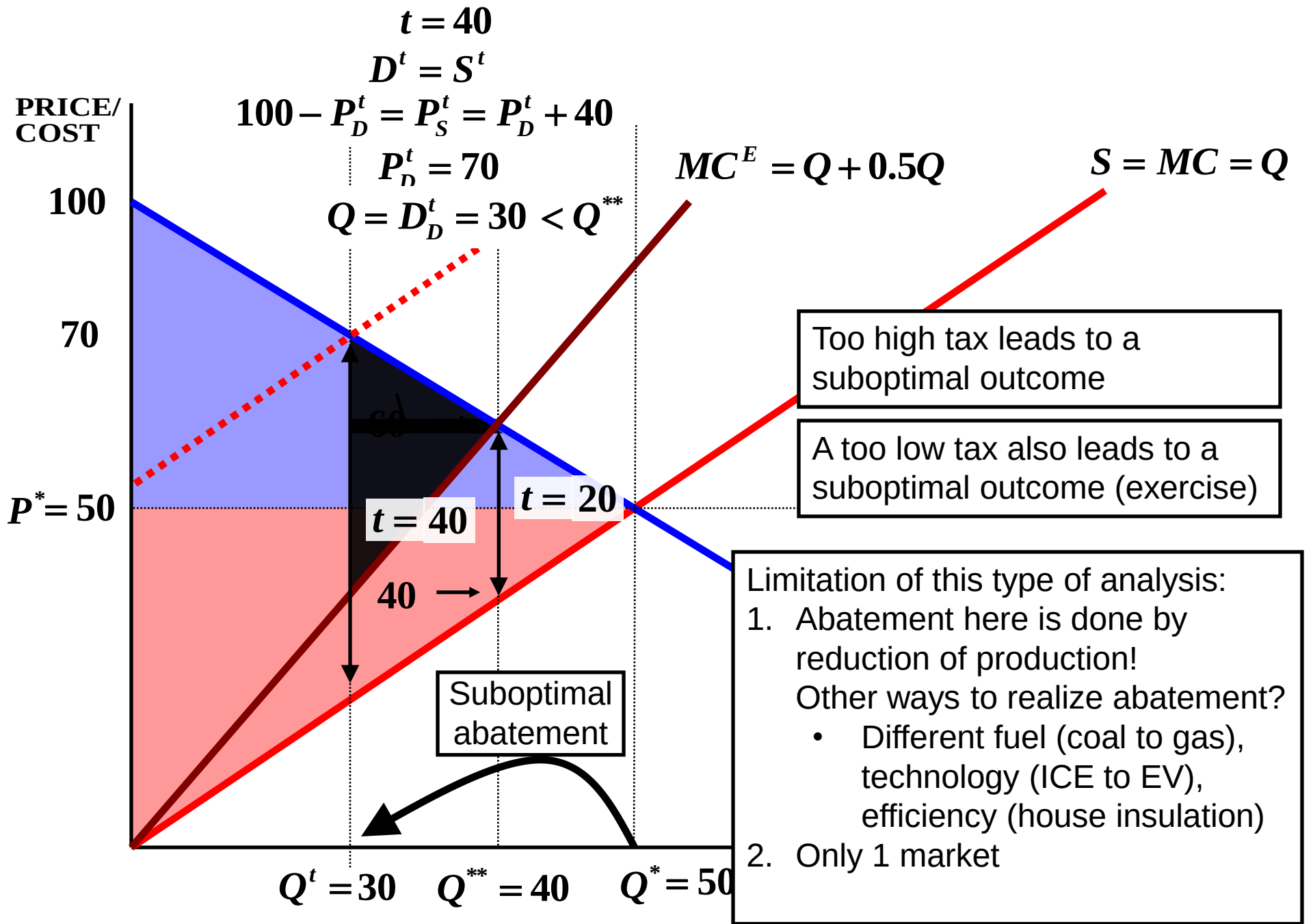
- A tax is a signal, not a punishment!
  /price

  Marcel Boiteux, testimony to the French National Assembly

- enables fine-tuned coordination
- Impossible to replicate by command & control
  - See failure of communist economics

  Hayek, F. A. (1945). The use of knowledge in society. The American economic review, 35(4), 519-530.

What if we make a mistake in estimating the externality?



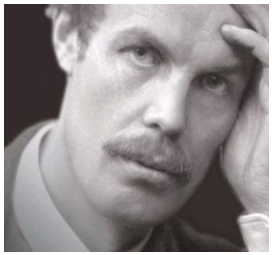
Too high tax leads to a suboptimal outcome

A too low tax also leads to a suboptimal outcome (exercise)

Limitation of this type of analysis:

1. Abatement here is done by reduction of production!
   Other ways to realize abatement?
   - Different fuel (coal to gas), technology (ICE to EV), efficiency (house insulation)
2. Only 1 market

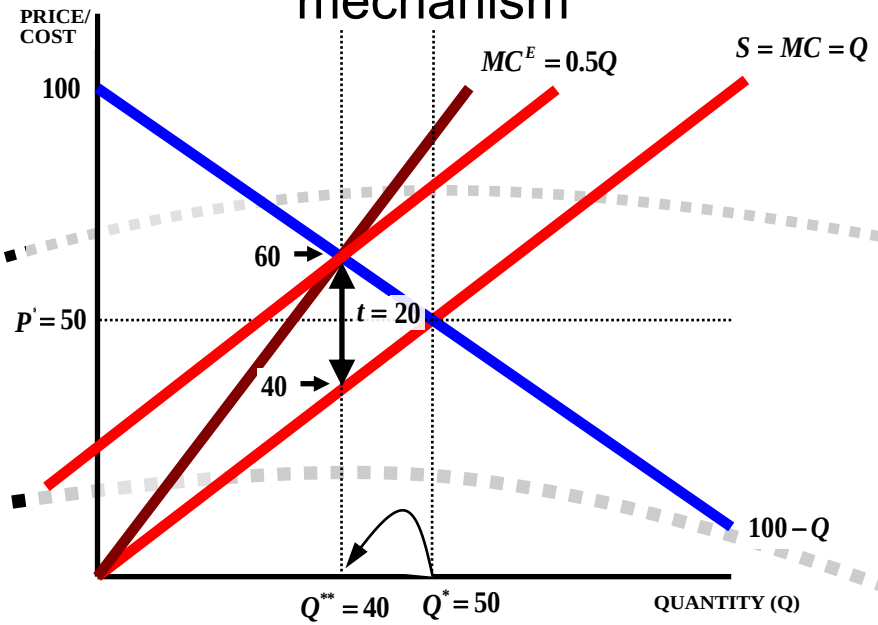
Carbon Taxation



Arthur Cecil Pigou (1877 –1959)

"economic mechanism"

Carbon price

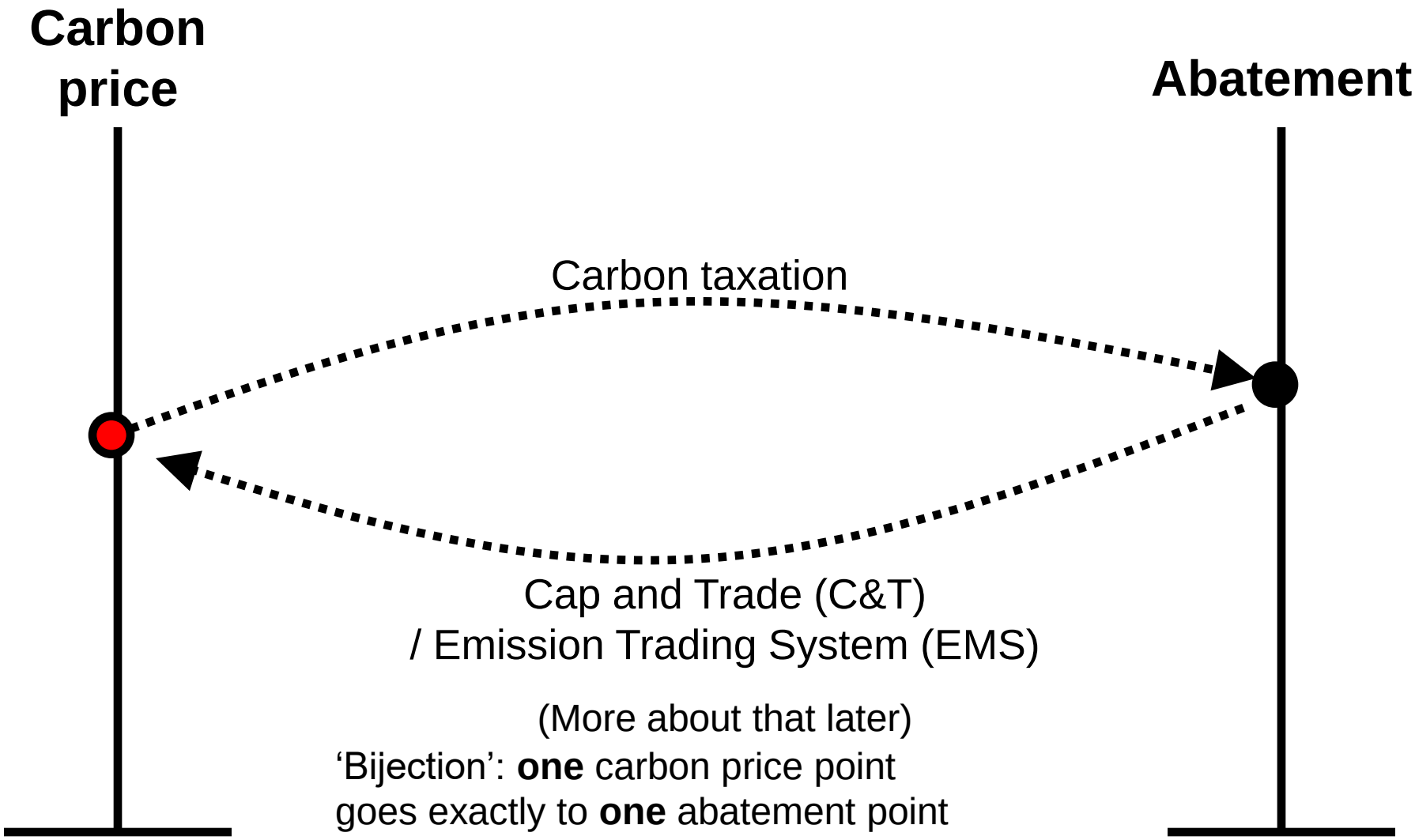


Abatement

'Bijection': **one** carbon price point goes exactly to **one** abatement point

(https://en.wikipedia.org/wiki/Bijection)

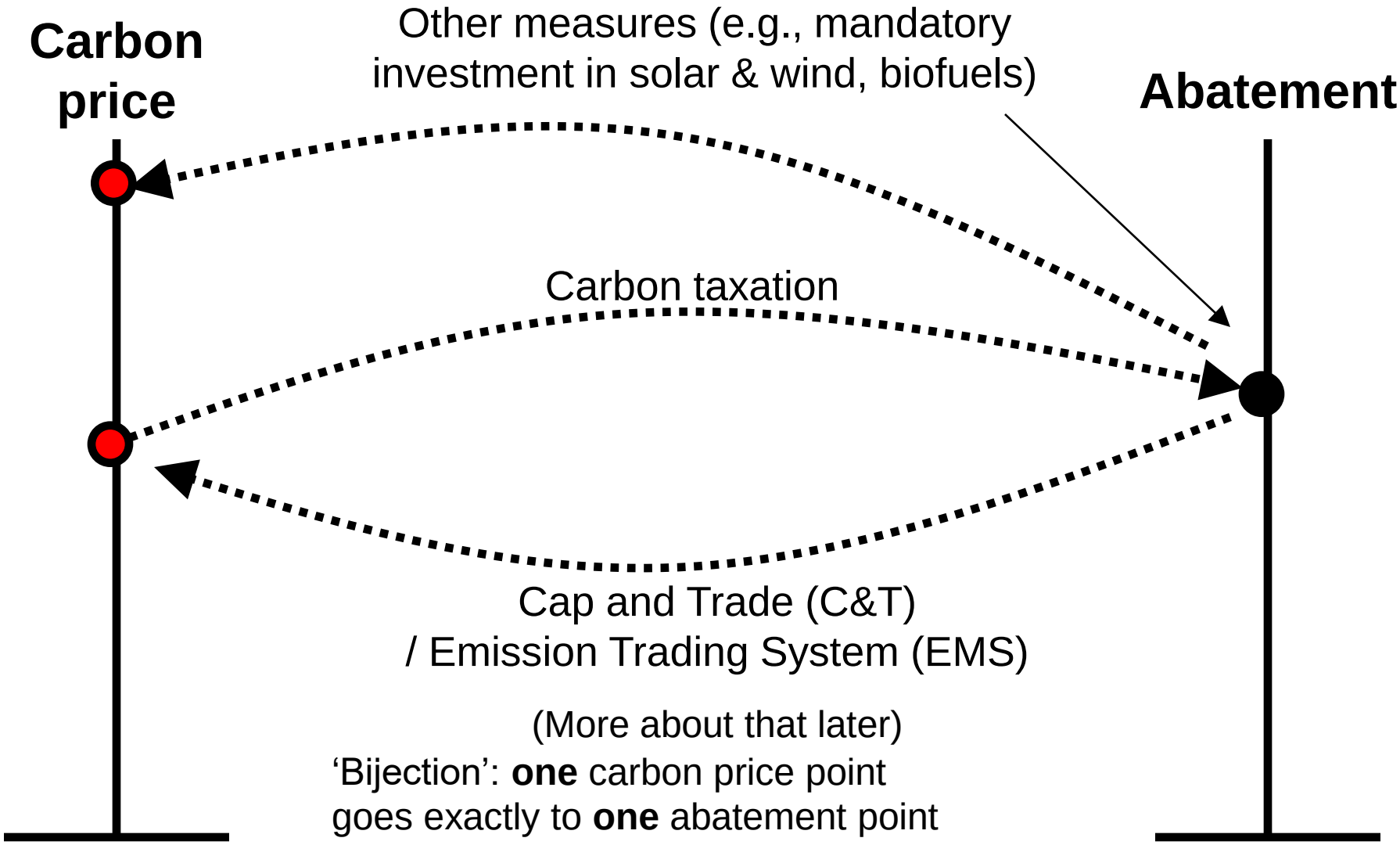
Carbon price & abatement



(More about that later)

‘Bijection’: **one** carbon price point
goes exactly to **one** abatement point

Carbon price & abatement



(More about that later)

‘Bijection’: **one** carbon price point goes exactly to **one** abatement point

- Even if you don’t want or cant implement taxes or ETS, this talk is still of interest.
- Because any amount of abatement reached by a measure has an implicit abatement cost
  - Costs: x euro
  - Abatement: y ton CO2
  - Av.batement cost = x/y euro/tCO2

- Any abatement measure average cost corresponds to a tax level.
  - (Tax level that would lead to the same level of abatement.)

- Cargo bike instead of car or pub. transport:
  - Saves tCO2 -> abates tCO2
- Berlin decides to subsidize
- Calculate $/abatement cost of subsidies
  - Calculate abatement cost of the subsidies for cargo bikes
  - Calculate how much tCO2 abated
  - Divide cost by abatement
    - -> $/abatement
- Compare to social cost of tCO2
  - Social cost = $40~ $80/tCO2
- Abatement cost of Berlin bike subsidy scheme?
  - **$60 000/tCO2**
    - (=$430 000 / 7 tCo2)
- **Example of government picking a “winner”**

http://www.economist.com/finance-and-economics/2021/02/22/what-is-the-cheapest-way-to-cut-carbon

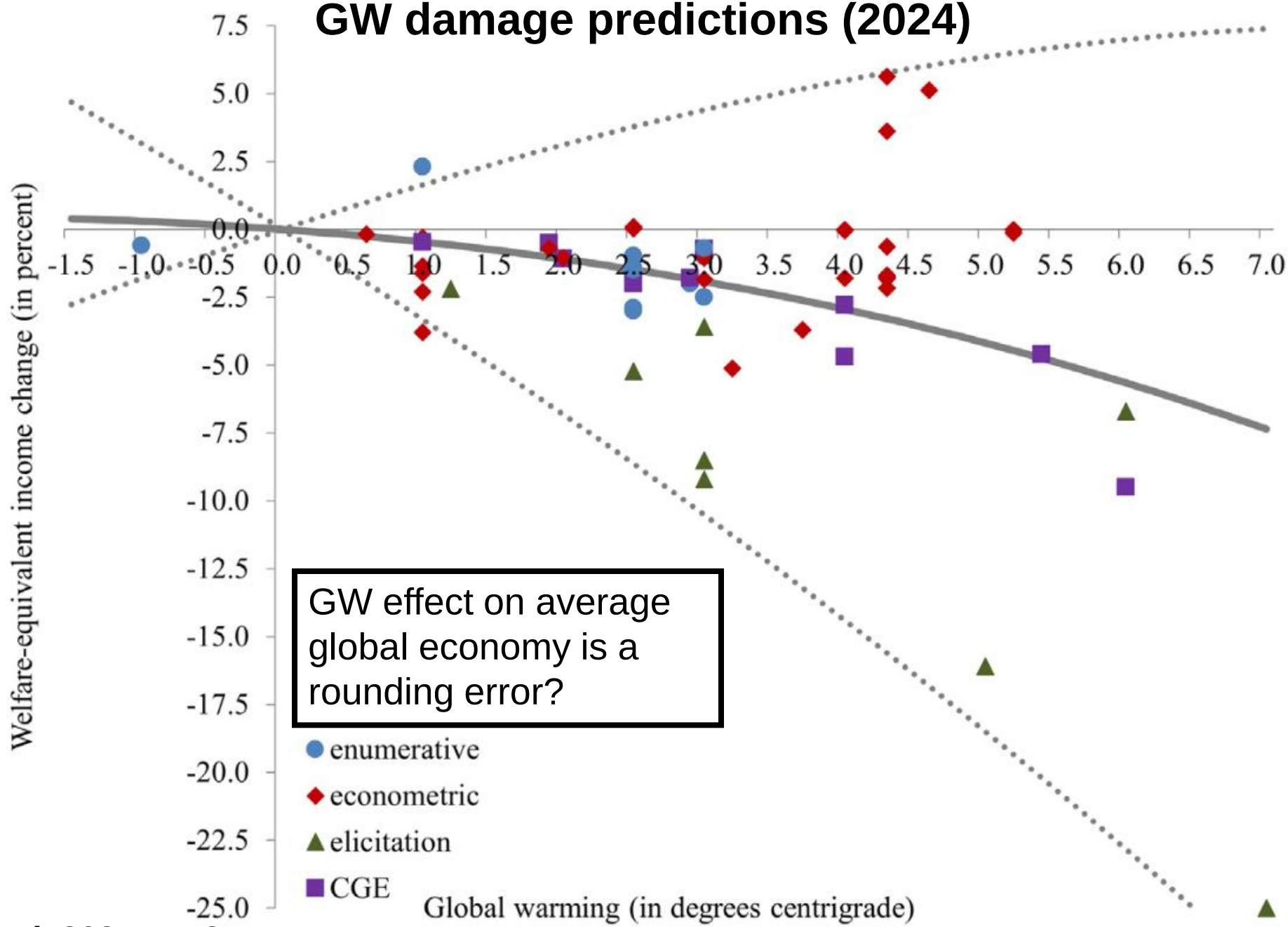
	Wind	Solar
• Marcantonini (2015, 2017)	• €55-160	€550-1000
• Abrell, Kosch and Rausch (JPE, 2019)	• €100-350,	€500-1700
• Greenstone, McDowell, & Nath (2019).	• $115	
• German Energy Blog, 2015	• €219	
• Muangjai et al (2020)(Thailand)	• $30	$150
• Compare with ETS	• €10/ton CO2	

- **2000-2020 EU** Renewable subsidy program was excessively ineffective and costly
  - 10x ~ 100x more expensive to alternative methods (ETS)
  - up to 17x~30x soc. marginal cost
- Waste of resources and precious time in EU
  - Now:
    - Auctions for renewables (improvement as is market-based instrument)

- How high should carbon tax be?
  - Carbon tax adds a marginal cost of emission
- In the optimal outcome:
  - Marginal cost = Marginal Benefit
- Benefit:
  - Avoiding cost of global warming
- Marginal Benefit of carbon tax
  - Marginal damage of global warming avoided

- In optimum:
  - **Carbon tax = Marginal damage**

GW damage predictions (2024)



Tol, 2024, p.184

- Global average growth 2000–2019?
  - 3.7%
- Total growth to 2100 if
  - 3.7%
    - **x15** (1.037^75) (-> +1400%)
  - 2%
    - **x4.4** (1.02^75) (-> +340%)
  - 1%?
    - **x2** (1.01^75) (-> +110%)

The marginal damage costs of carbon dioxide emissions in $\$^{2015}$/tC

	all	3%	1%	0%
mode	68	28	34	104
median	295	38	64	269
mean	397	42	80	346
st dev	463	34	80	314
5^{th} %ile	-173	-8	-17	139
95^{th} %ile	1249	101	232	897

- 40 €^{2025} 3% discount
- 100 €^{2025} 1% discount

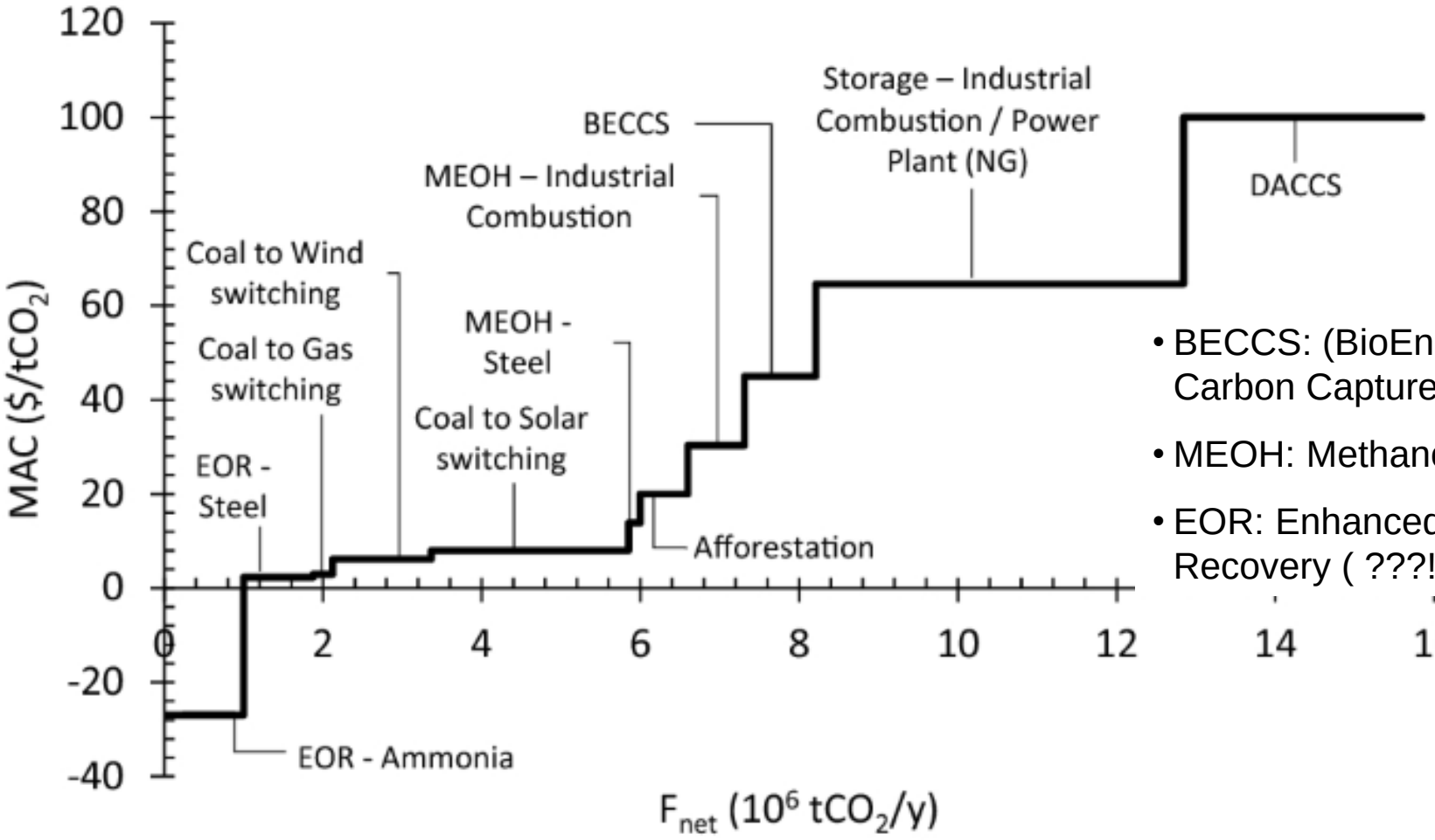
- Abatement is achieved by:
  1. reducing production
  2. changing technology (ICE to EV)
  3. different fuel (coal to gas)
  4. efficiency (house insulation, heat pumps)

We looked at that

We didn't look at that

- Marginal abatement costs
  - The cost of abating one more ton of CO2
  - Any possible way of abatement included!
  - Can be used to look at the interaction between different firms and different markets

- We often use Marginal Abatement Cost curves to show the cost for a firm to reduce emissions.
- Horizontal line: The total reduction of emissions.
- Vertical line: The marginal cost of abatement.

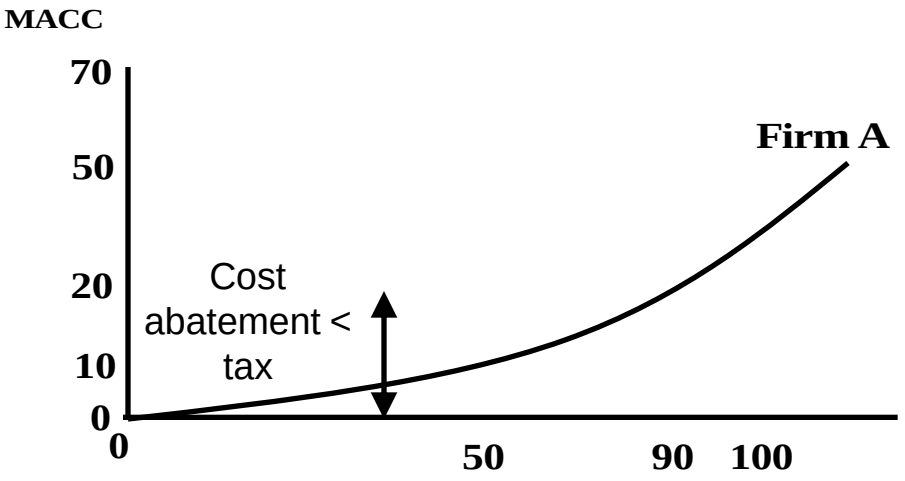


- BECCS: (BioEnergy with Carbon Capture & Storage)
- MEOH: Methanol fuel
- EOR: Enhanced Oil Recovery (???!!!) 😠

https://link.springer.com/article/10.1007/s10098-021-02095-y

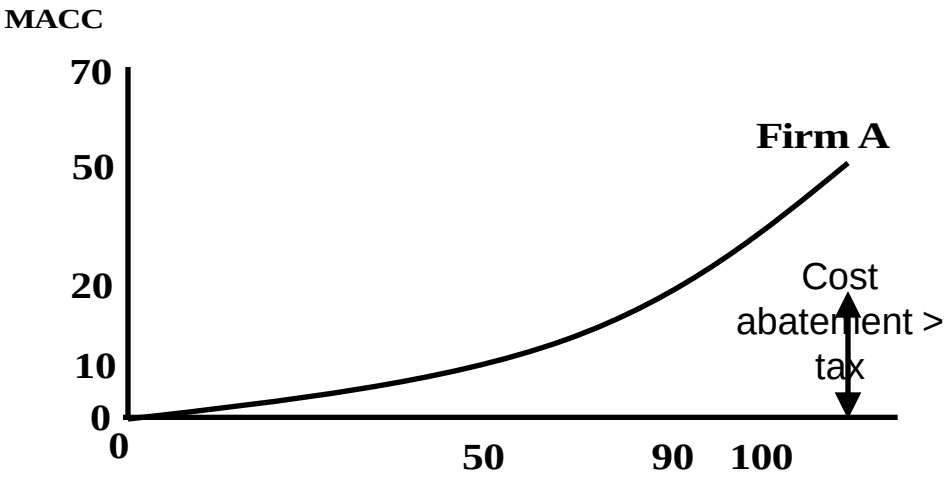
Use MACC to analyze abatement choices

$$t = 20$$



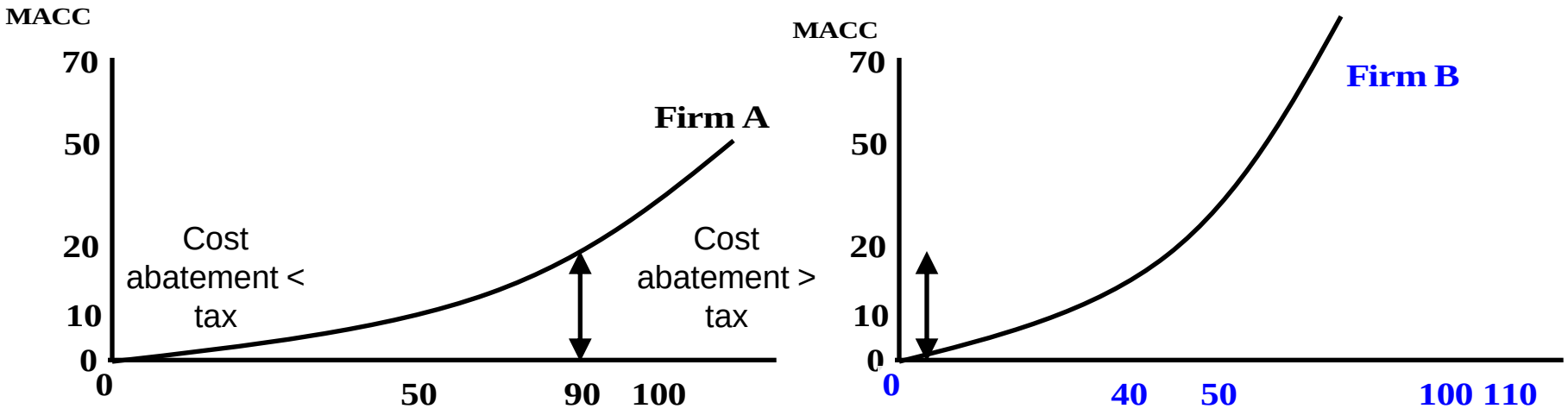
Use MACC to analyze abatement choices

$$t = 20$$



Use MACC to analyze abatement choices

$t = 20$

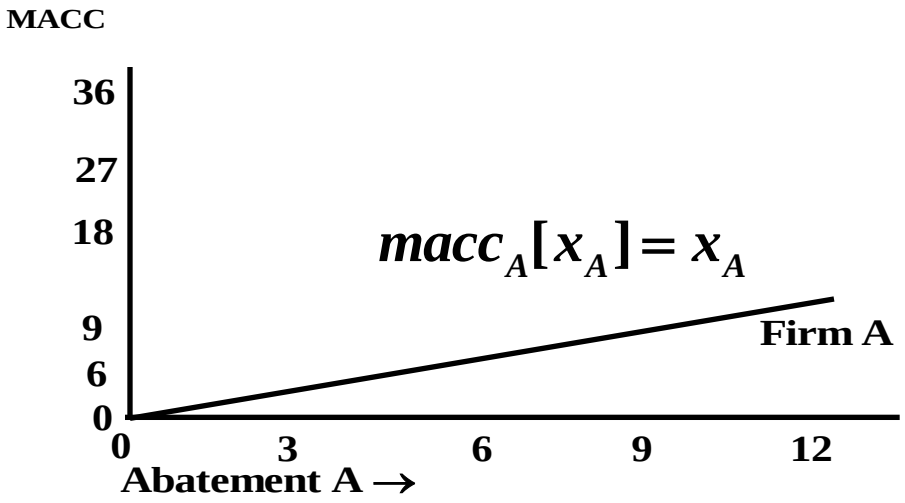


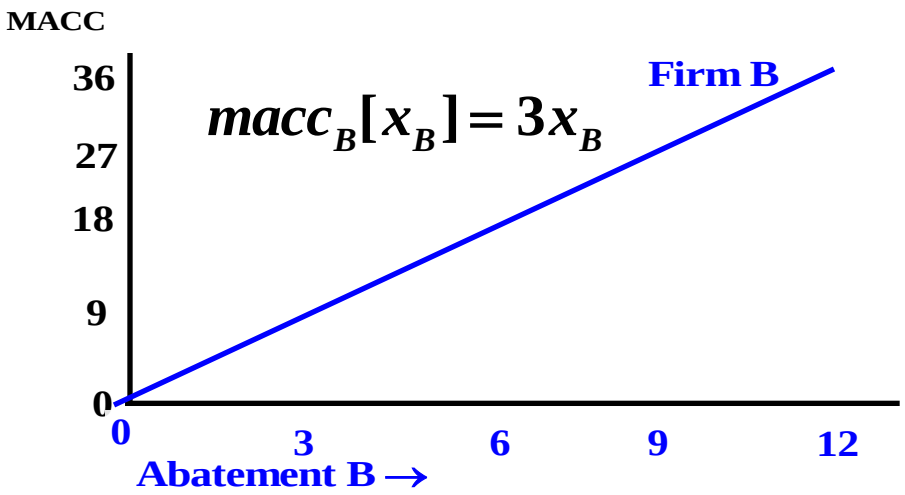
The tax works as a perfect coordination method! And makes different firms abate different amounts (which is optimal)!

Government doesn't need to know each firm's individual MACC for optimal coordination!!!

Analyze more closely with simpler MACCs

Use MACC to analyze abatement choices



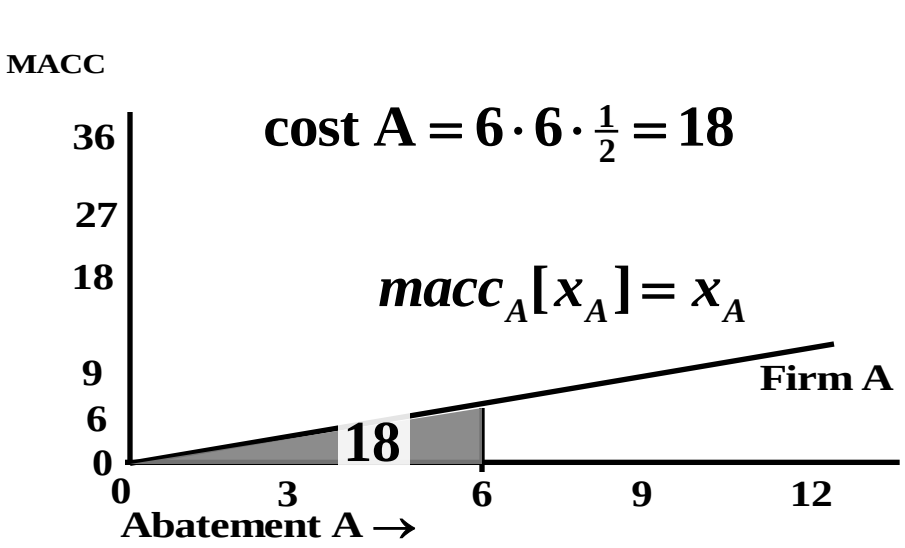


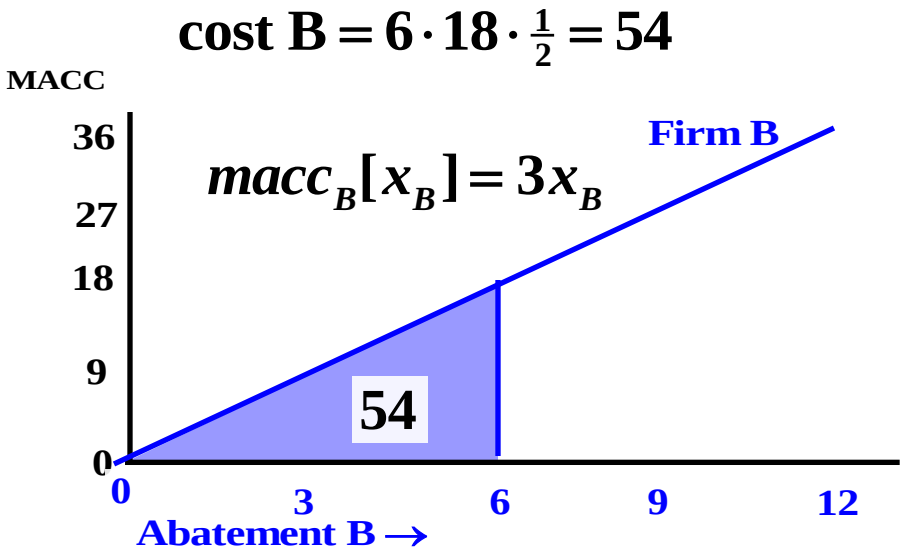
We need abatement of 12 units

- Let us compare two measures

1. Regulatory standards
   - Just give all firms the order to reduce pollution.
   - For example, all the same amount: 6 units each
2. Use a carbon tax

Suppose we have two firms



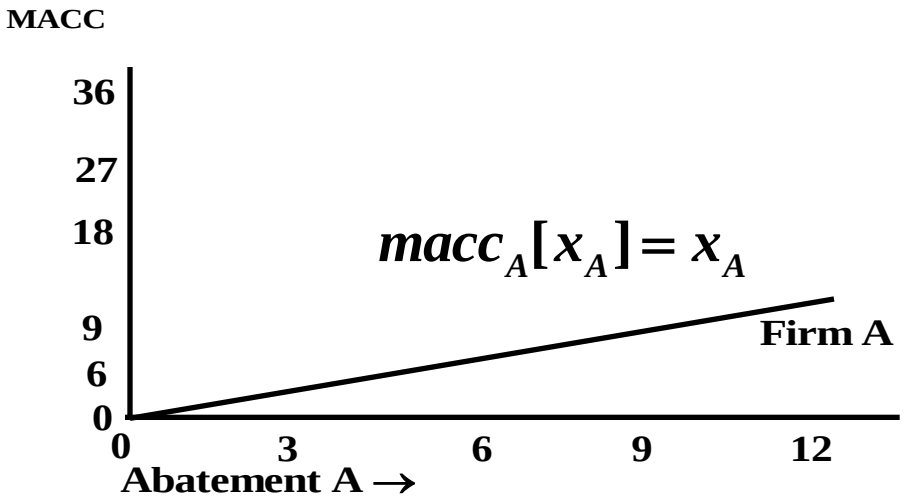


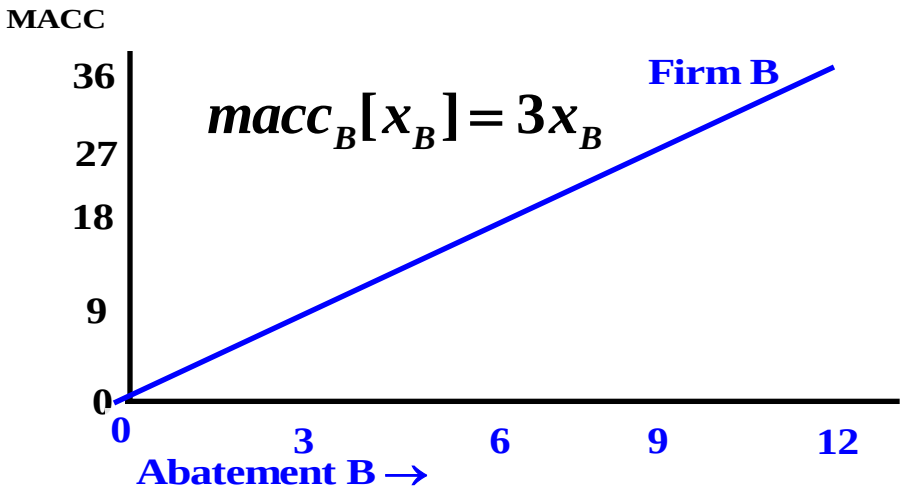
We need abatement of 12 units

1.Regulatory standards

- Each has to reduce pollution by 6 units
- What are the abatement costs?
- 18+54 = 72$

Carbon tax





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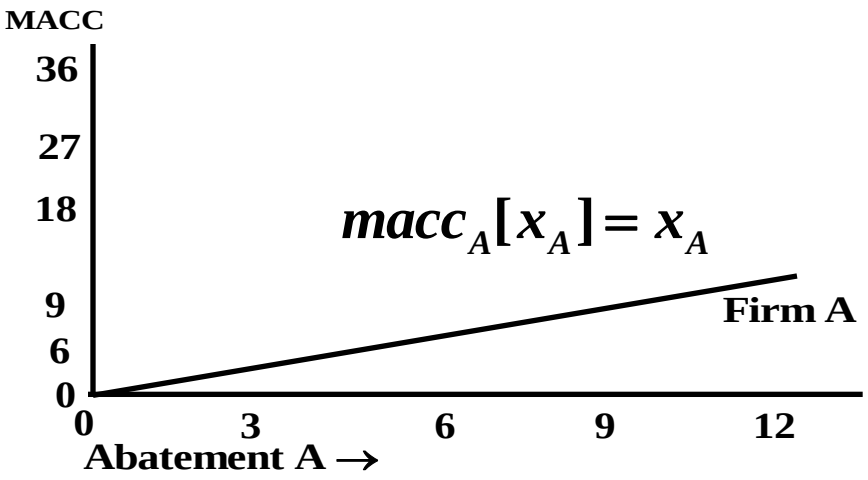
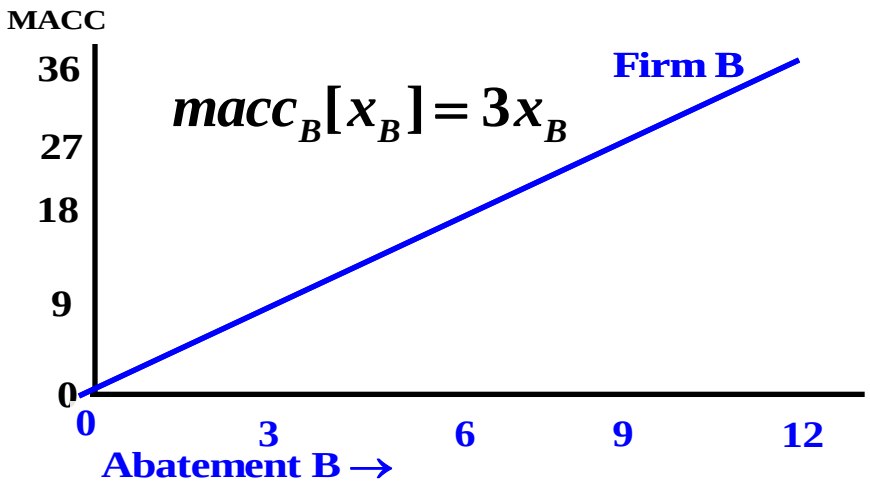
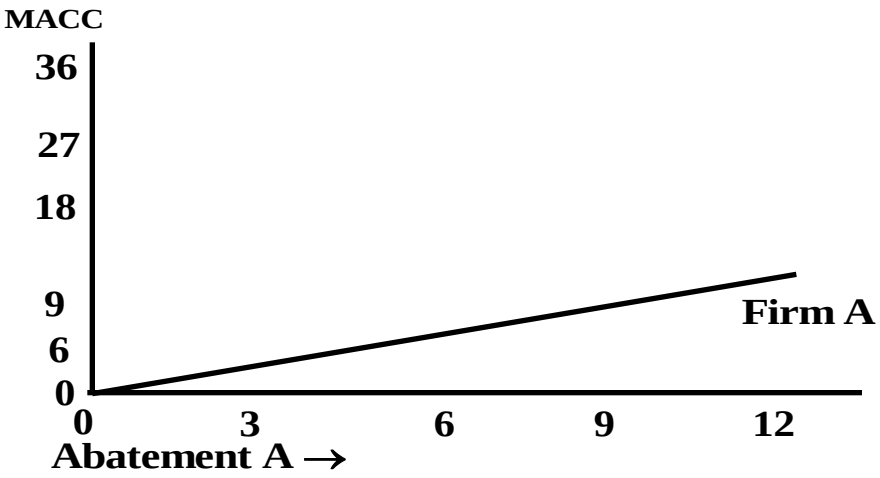
Carbon tax

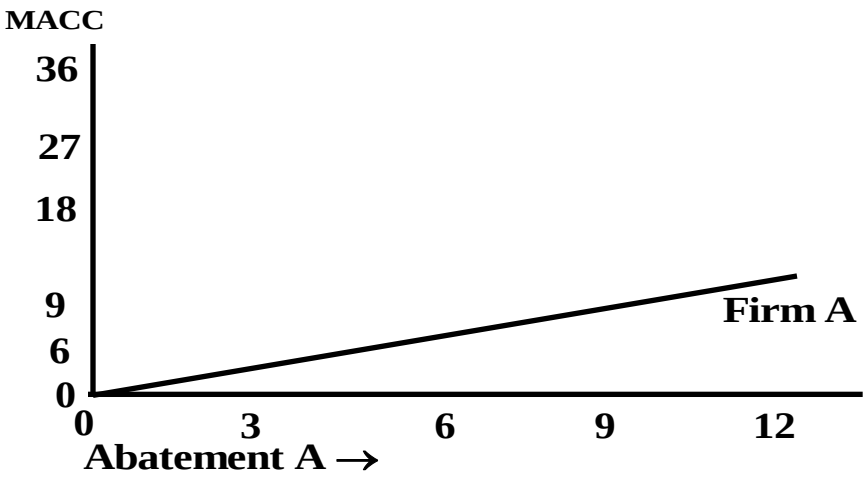


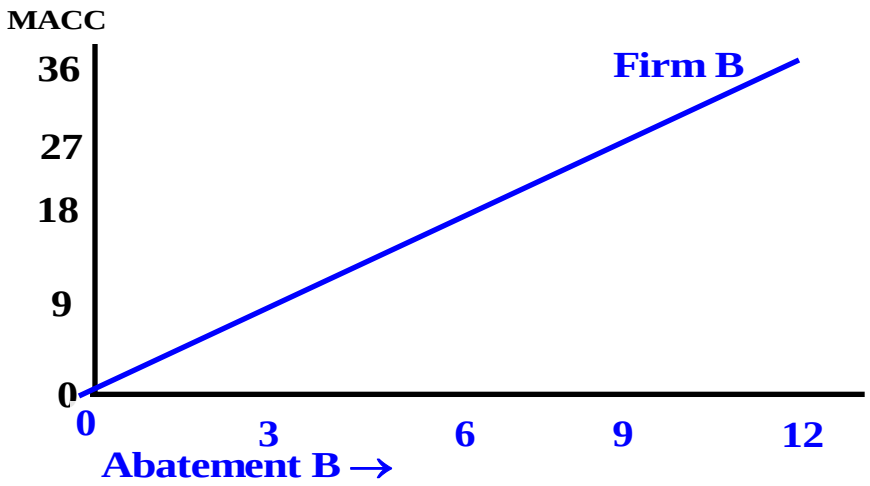


We need abatement of 12 units

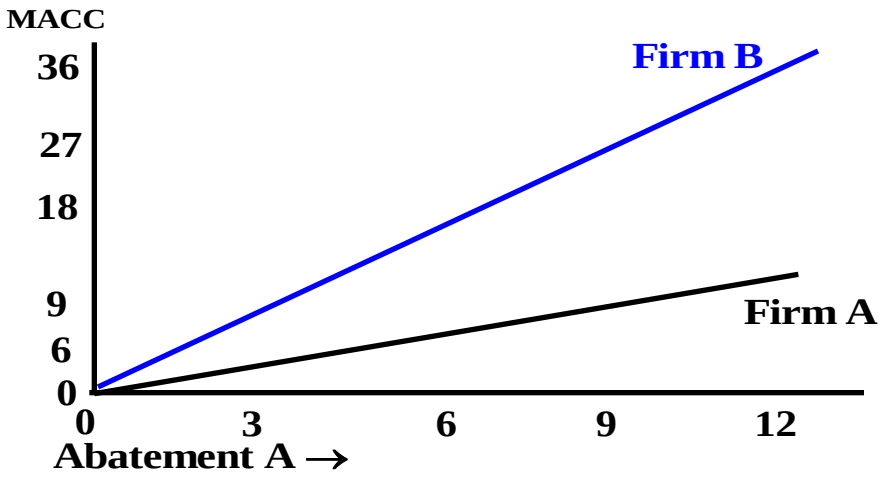


Carbon tax





We need abatement of 12 units



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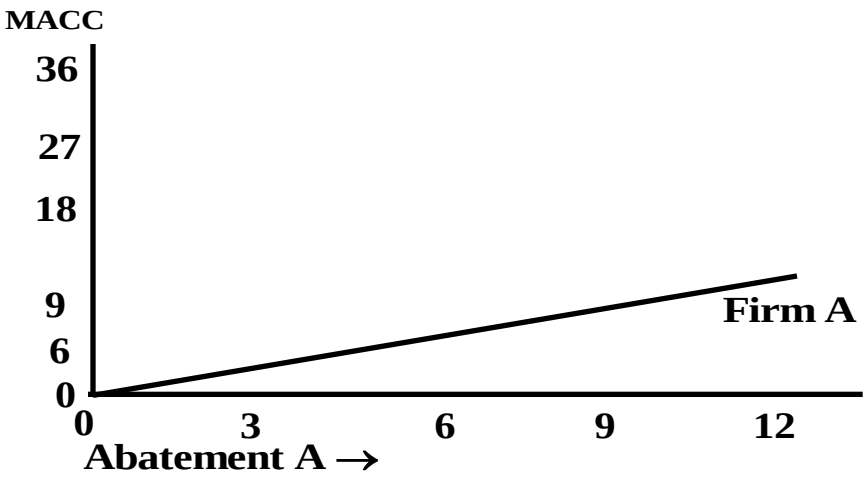
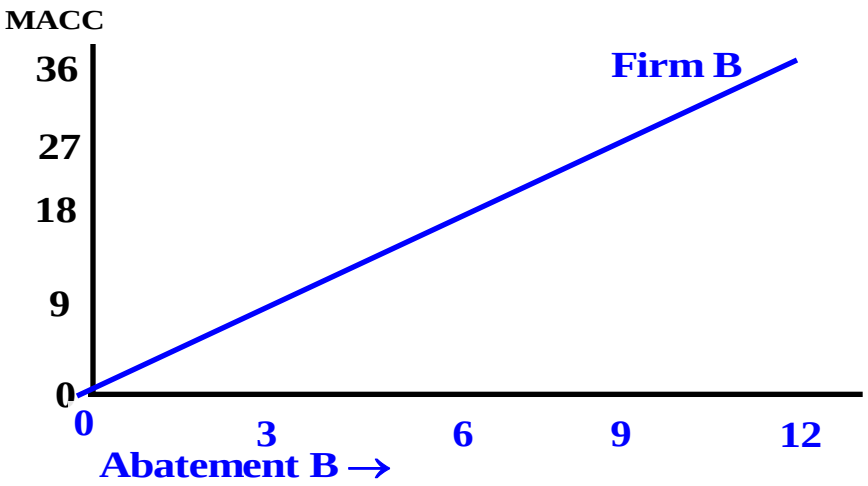
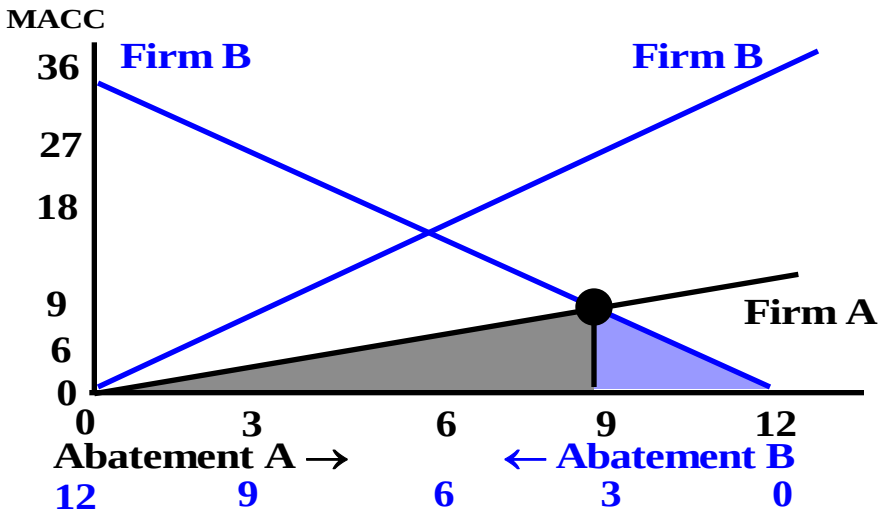




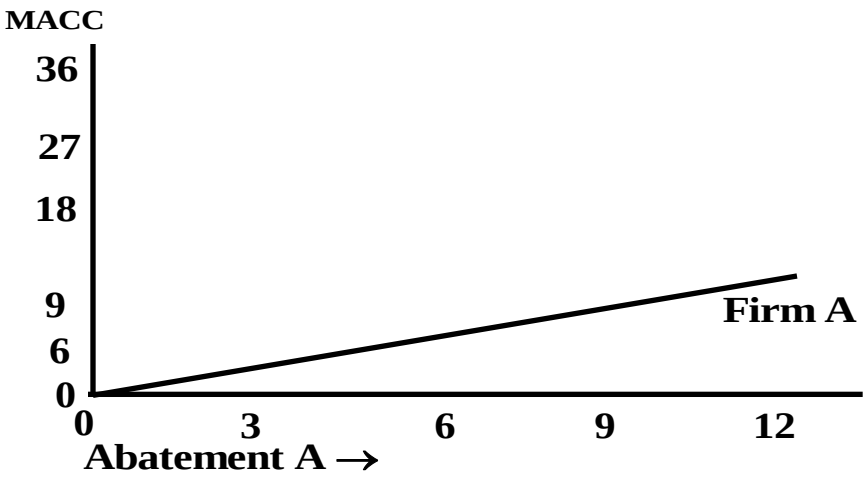
We need abatement of 12 units

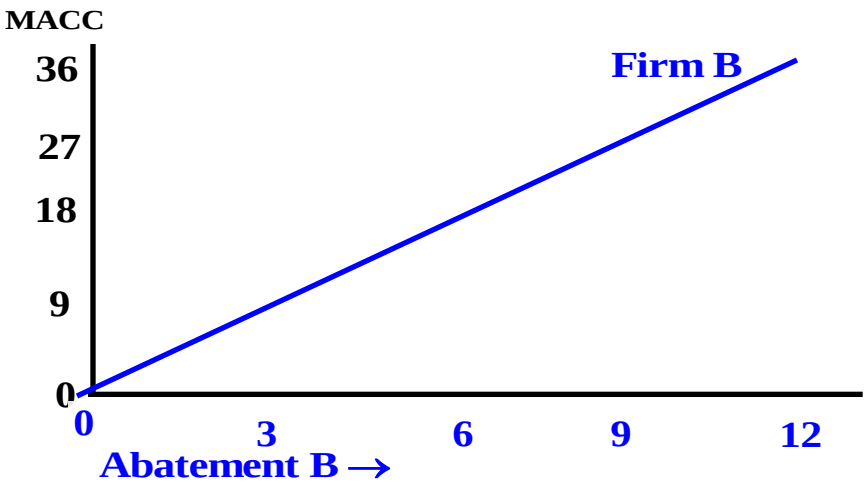
$$\text{cost A} = 9 \cdot 9 \cdot \tfrac{1}{2} = 40.5 \qquad \text{cost B} = 9 \cdot 3 \cdot \tfrac{1}{2} = 13.5$$



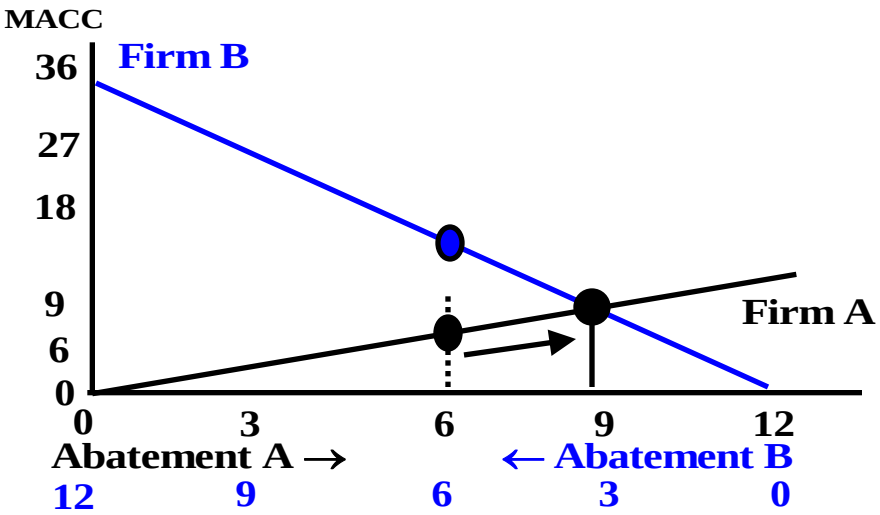
Intersection at A:9, B:3
Any other point is suboptimal. Why?
MACC of A and B must be equal
What is the tax rate?
Tax = 9
What are the abatement costs?
40.5+13.5=54$
Cheaper than regulatory standards!
(54$ < 74$)

Carbon tax





We need abatement of 12 units

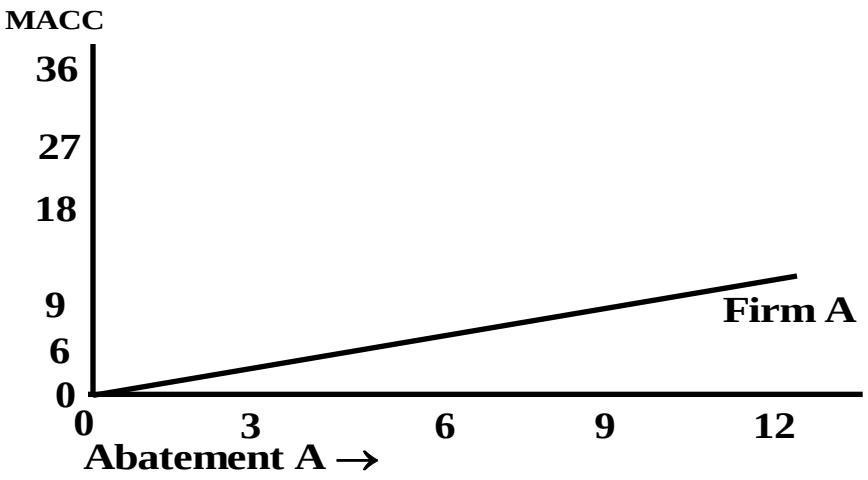


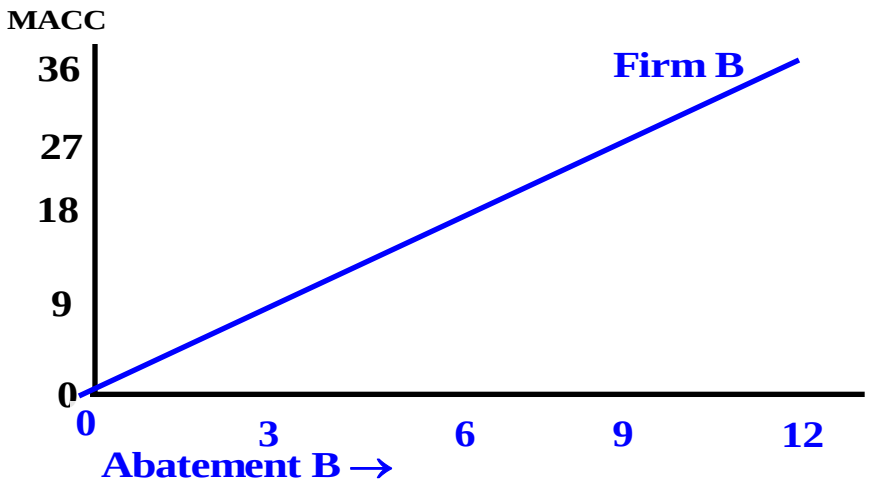
Suppose:
- Tax = 9
- The start position is A:6, B:6

What would happen?

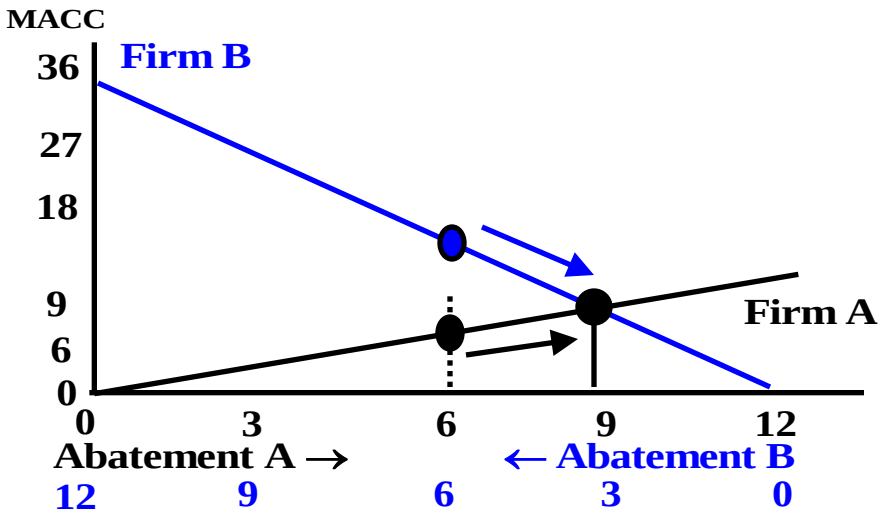
- For each unit A abates, he does not need to pay the tax of 9$
- Abating a unit costs now 6$
- So A wants to abate more

Carbon tax





We need abatement of 12 units



Suppose:
- Tax = 9
- The start position is A:6, B:6

What would happen?

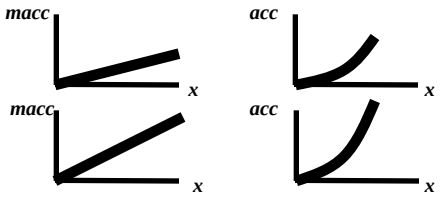
- For each unit B abates, he does not need to pay the tax of 9$
- Abating a unit costs B now 18$
- So B wants to abate less

- With some mathematics, this analysis can be done more directly

Compare the efficiency of carbon taxation with regulatory standards (command-and-control regulation)

- Suppose we found out we must reduce emission by 12 units. We have two firms

$$macc_A[x_A] = x_A \qquad acc_A[x_A] = \tfrac{1}{2}x_A^2$$
$$macc_B[x_B] = 3x_B \qquad acc_B[x_B] = \tfrac{3}{2}x_B^2$$



regulatory standards

- Each firm reduces emissions by 6

$$ac_A = \tfrac{1}{2}\cdot 6^2 = 18$$
$$+\ ac_B = \tfrac{3}{2}\cdot 6^2 = \tfrac{3}{2}\cdot 36 = 54$$
$$Tac = 18 + 54 = 72$$

Carbon tax

$$macc_A = macc_B = t$$
$$x_A = 3x_B = t$$
$$x_A = 9$$
$$t = 9$$

$$x_A + x_B = 12$$
$$3x_B + x_B = 12$$
$$\Leftrightarrow \quad x_B = 3$$

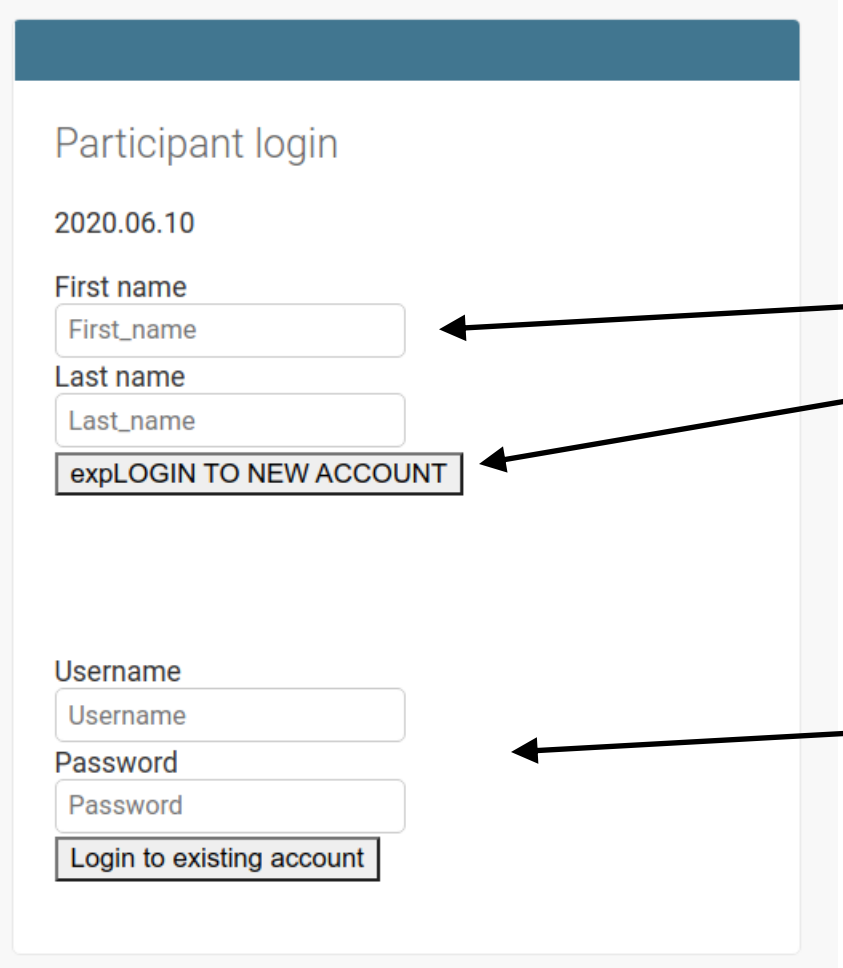
$$ac_A = \tfrac{1}{2}\cdot 9^2 = 40.5$$
$$+\ ac_B = \tfrac{3}{2}\cdot 3^2 = 13.5$$
$$Tac = 40.5 + 13.5 = 54$$

Experiment dAuction

- Put into chrome browser address:
- **https://bit.ly/dexperiment** or 147.251.124.246

Experiment dAuction

- Put into webbrowser the address:
- **https://bit.ly/dexperiment** or 147.251.124.246



Fill out at least one field and click on the LOGIN

ignore

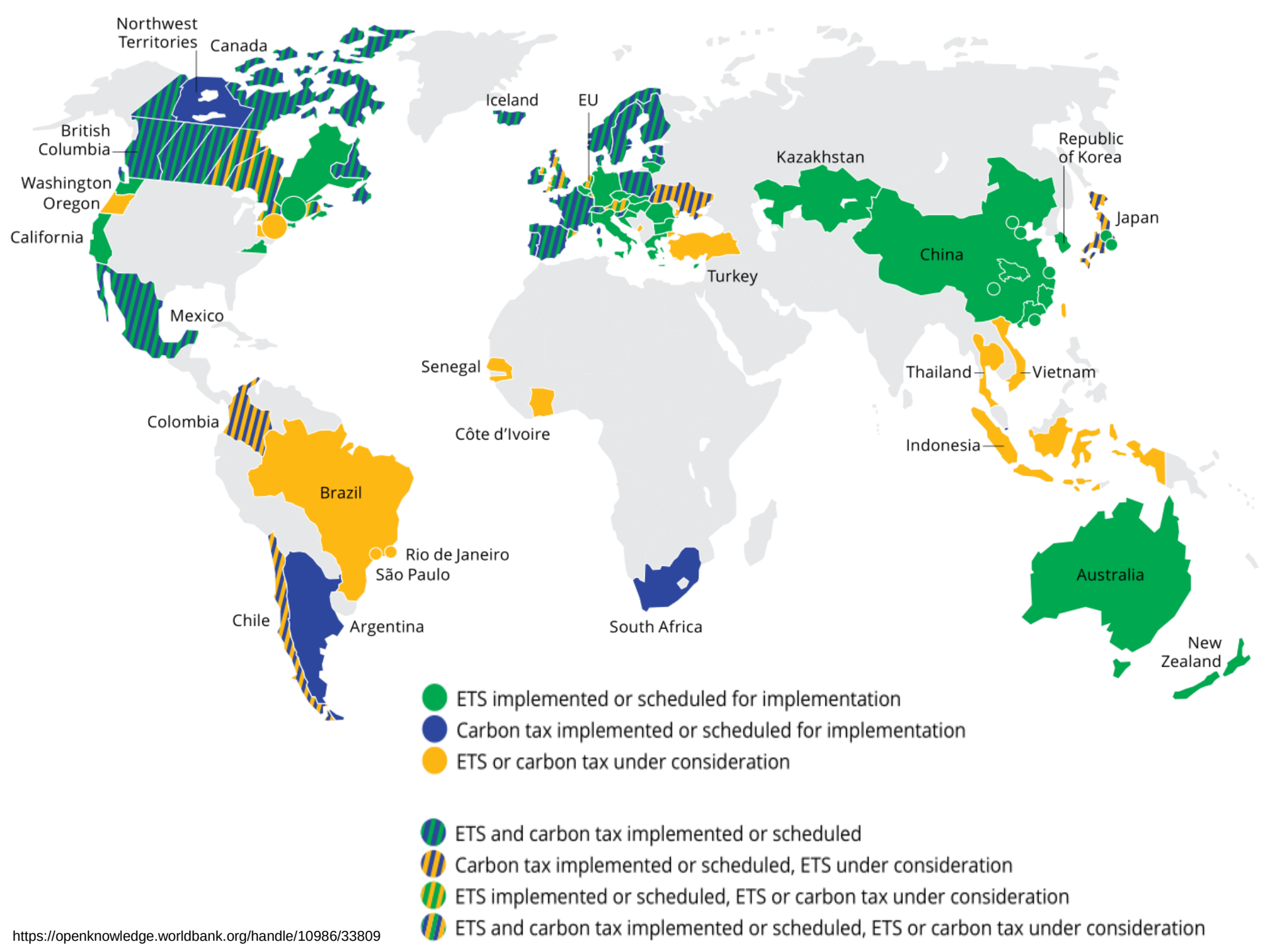
- What else to do now for economists (or even politicians)?
  - Nothing much
  - The externality has been addressed
  - The job has been done
  - This is the best we can get.
    - Improve decisions
      - Providing information
      - Probably still some minor adjustments
    - Efforts for better estimates of the optimal level of the carbon tax
    - (The marginal cost of CO2)

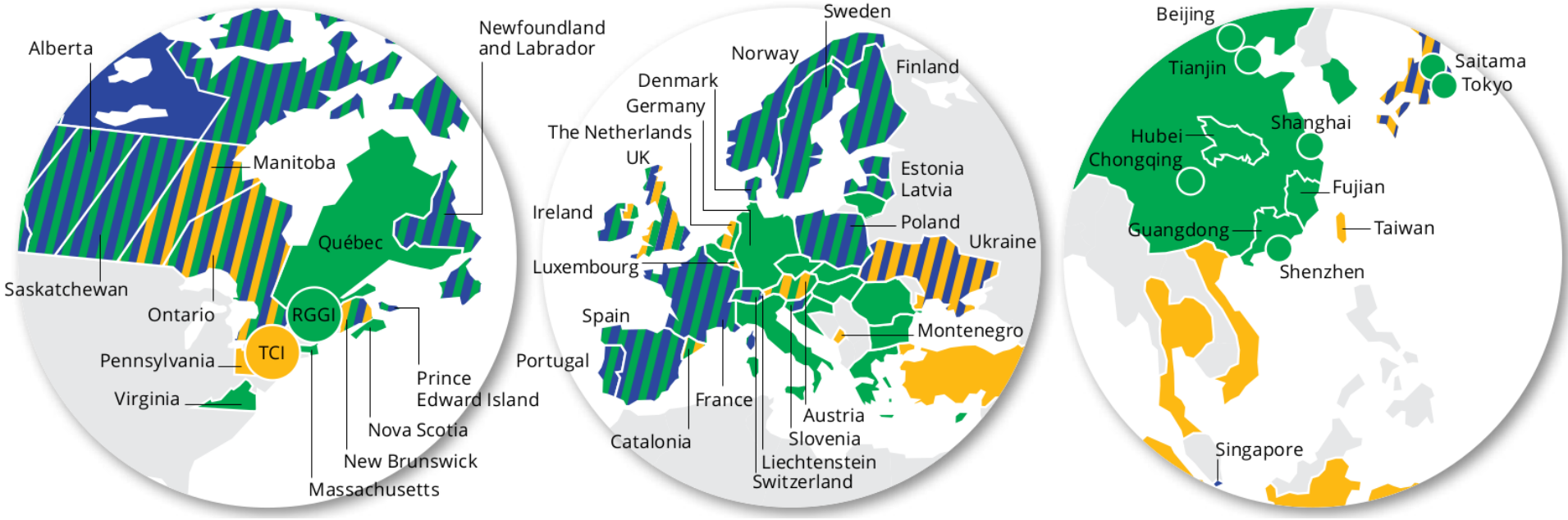
- Shouldn't we still subsidize renewables, subsidize efficiency improvements?
  - In theory, no. Only if there are very specific additional market failures.
  - Most subsidies are partially ineffective, inefficient and expensive.
    - Measure of last resort (if you cannot make people pay tax)

- What to use the revenues for?
- Optimal (based on econ. analysis):
  1. Use it to address other externalities
     - Research
     - Lower income or business tax
  2. Divide equally among the population
- Suboptimal (not supported by econ. analysis):
  1. Give subsidies for mass-deployment to technologies favored by politicians/engineers
     - (at least 50% of revenue is spent this way in most places)

Economics of pollution

1. Refresh free market economics basics ✓
2. Introduce carbon emissions as an externality ✓
3. Introduce 2 possible solutions
    1. Carbon Tax ✓
    2. *Emission Trading Scheme (ETS)* ✓
4. Overview carbon taxation & ETS in the world
5. How well is EU ETS doing?



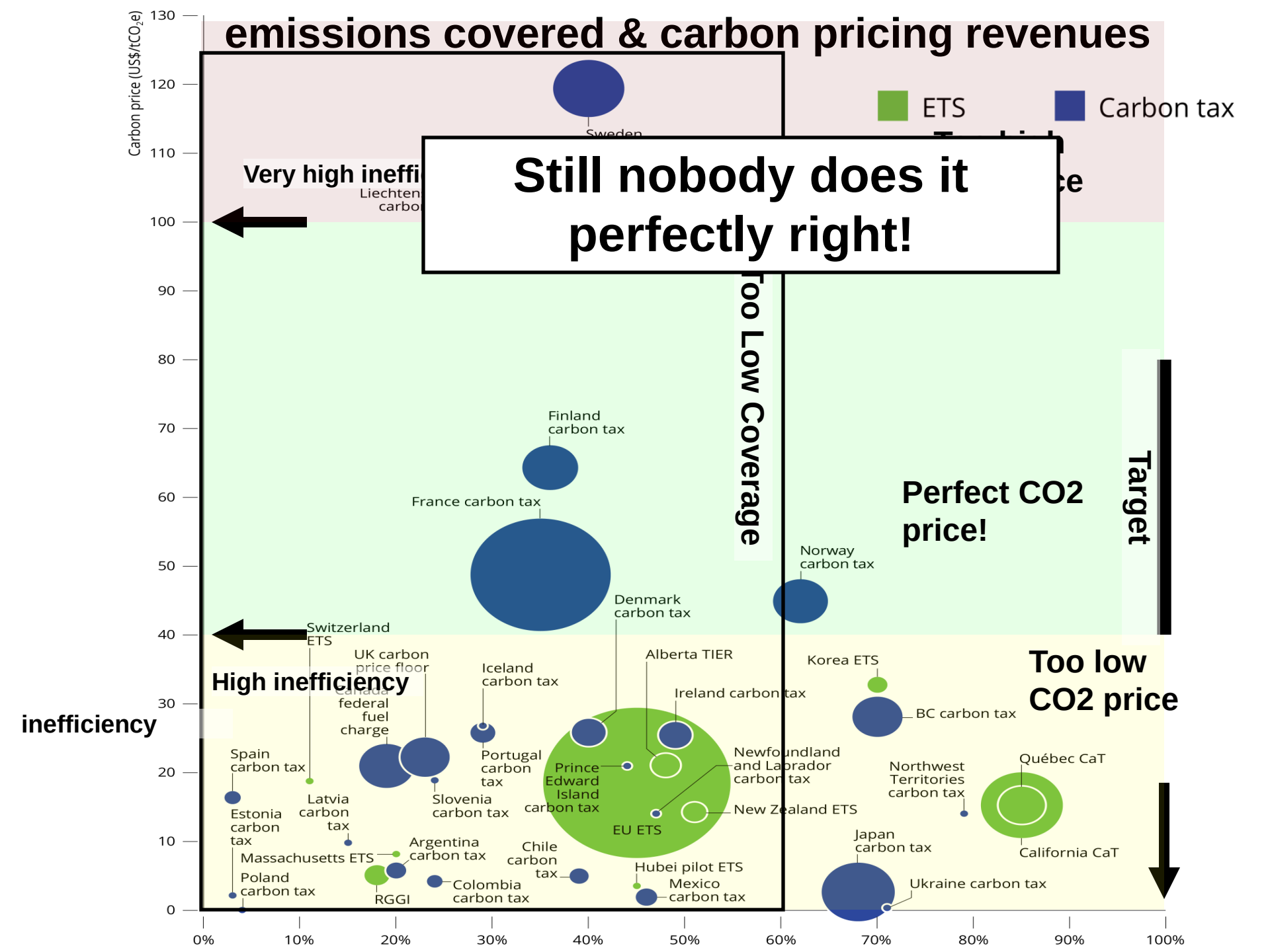


- All EU member countries have Emission Trading System (ETS)
- So many countries are considering to add a tax on top!
  - (Why have ETS ***and*** carbon tax?)

ETS implemented or scheduled for implementation
Carbon tax implemented or scheduled for implementation
ETS or carbon tax under consideration

ETS and carbon tax implemented or scheduled
Carbon tax implemented or scheduled, ETS under consideration
ETS implemented or scheduled, ETS or carbon tax under consideration
ETS and carbon tax implemented or scheduled, ETS or carbon tax under consideration

https://openknowledge.worldbank.org/handle/10986/35620


emissions covered & carbon pricing revenues
ETS
Carbon tax
Carbon price (US$/tCO2e)
Still nobody does it perfectly right!
Very high ineffi
Too Low Coverage
Perfect CO2 price!
Target
High inefficiency
Too low CO2 price
inefficiency
Sweden
Finland carbon tax
France carbon tax
Norway carbon tax
Denmark carbon tax
Switzerland ETS
UK carbon price floor
Iceland carbon tax
Alberta TIER
Ireland carbon tax
Korea ETS
BC carbon tax
Canada federal fuel charge
Spain carbon tax
Portugal carbon tax
Prince Edward Island carbon tax
Newfoundland and Labrador carbon tax
Québec CaT
Northwest Territories carbon tax
Estonia carbon tax
Latvia carbon tax
Slovenia carbon tax
EU ETS
New Zealand ETS
Japan carbon tax
California CaT
Massachusetts ETS
Argentina carbon tax
Chile carbon tax
Hubei pilot ETS
Poland carbon tax
RGGI
Colombia carbon tax
Mexico carbon tax
Ukraine carbon tax
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
10
20
30
40
50
60
70
80
90
100
110
120
130

ETS & tax: Dutch carbon price floor for industrial emissions

Year	Floor price EUR/ tCO2	Year	Floor price EUR/ tCO2
2021	30.00	2026	82.80
2022	40.56	2027	93.36
2023	51.12	2028	103.92
2024	61.68	2029	114.48
2025	72.24	2030	125.04

- Only in NL!
- Addition = Min(0, price floor - price EU ETS permit)
- Thus, either
  - Addition = price floor - price EU ETS permit, when
    - price ETS permit < floor

  or
  - Addition =0
    - price ETS permit > floor

policies in dark red colored font are not necessary economically efficient

Year	Floor price EUR/ tCO2
2028	103.92
2029	114.48
2030	125.04

- Why price floor > estimated marginal carbon damage?
  - Lowers welfare by overdecarbonizing

- To be in line with economic insights, policy needs additional justification.
- Examples of possible justifications:
  - research showing marginal carbon damage > 80E/ tCO2
  - arguments for an abundance of caution specifically for NL
    - (NL has perhaps an outlandish effect on GW???)
    - (it has not)

Economics of pollution

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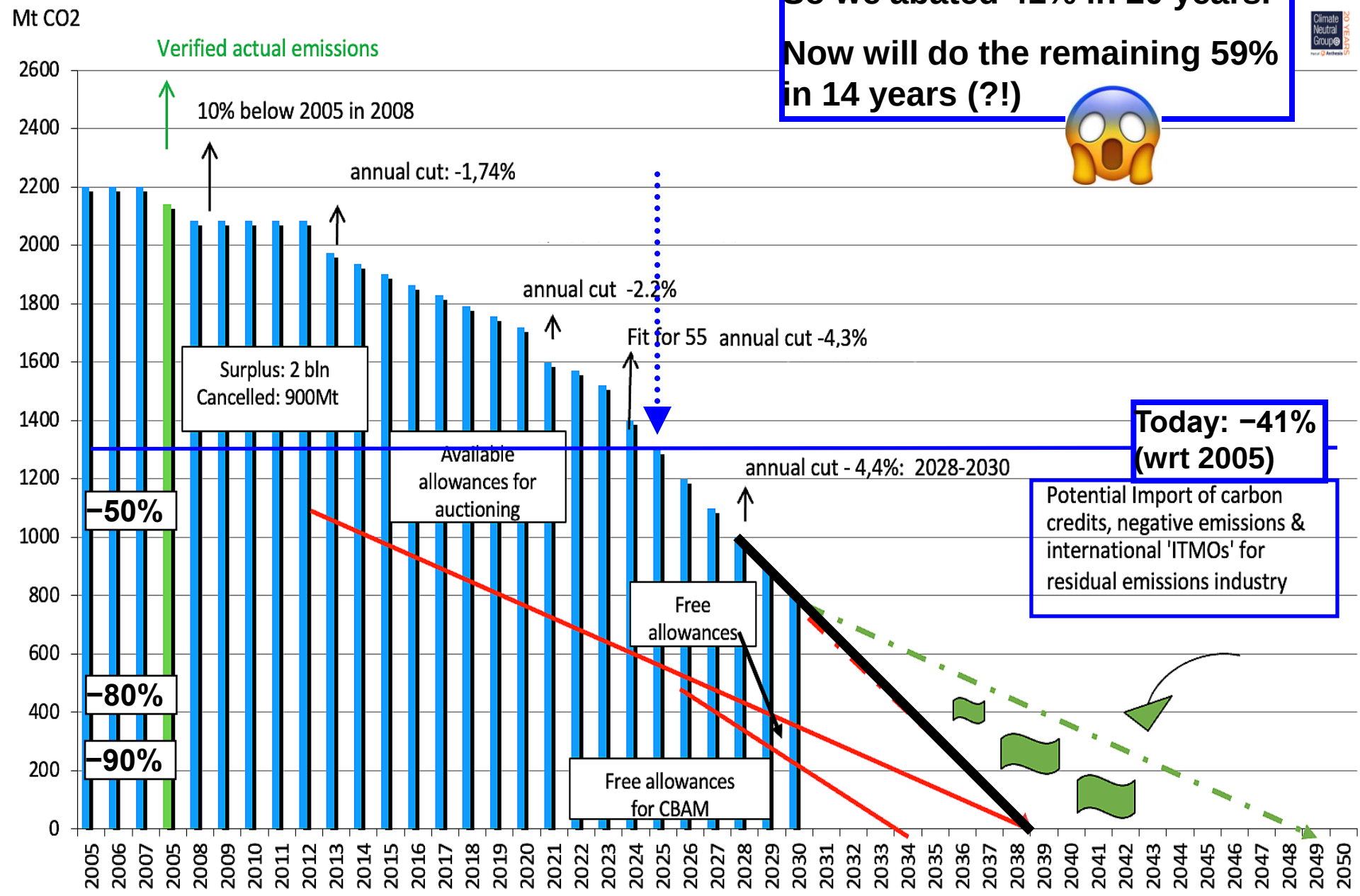
4. Overview carbon taxation & ETS in the world ✓
5. How well is EU ETS doing?

Decarbonization plans w. pro & cons

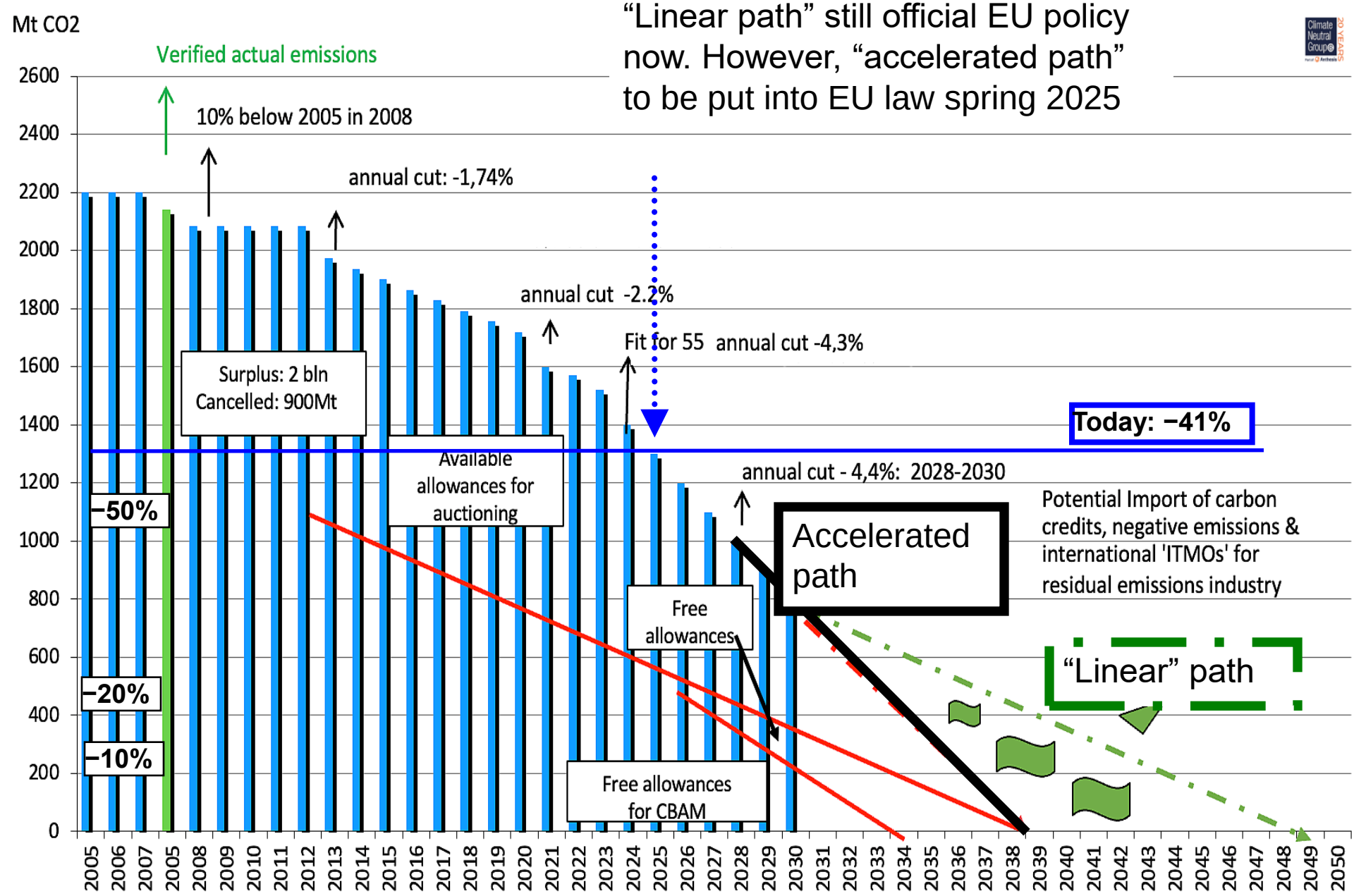
1. Explicit emission pricing
   - Pro: Efficient if price/abatement is set correctly
   - Dangers:
     - Inefficiently low or high pricing (floor tax)
     - inefficiently low or high abatement (ETS)
     - wasting of revenue by government or special interests

2. Standards and regulations &
3. Complementary policies
   - Pro:
     - Address some market failures
     - Soften income impacts
   - Danger:
     - Inefficient micromanagement
     - Capture of subsidies by special interests (solar/wind/battery producers)

1. Explicit emission pricing
   - ETS
     - Covers 40% of EU GHG emissions
       - Plans to increase with ETS2!
     - electricity and heat generation
     - industrial manufacturing
     - Aviation & maritime transport
       - https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/scope-eu-ets_en
   - Carbon taxes as price floors
     - Some countries have this as additional measures



https://www.emissierechten.nl/column/tightening-eu-ets-leads-to-zero-emissions-before-2040/

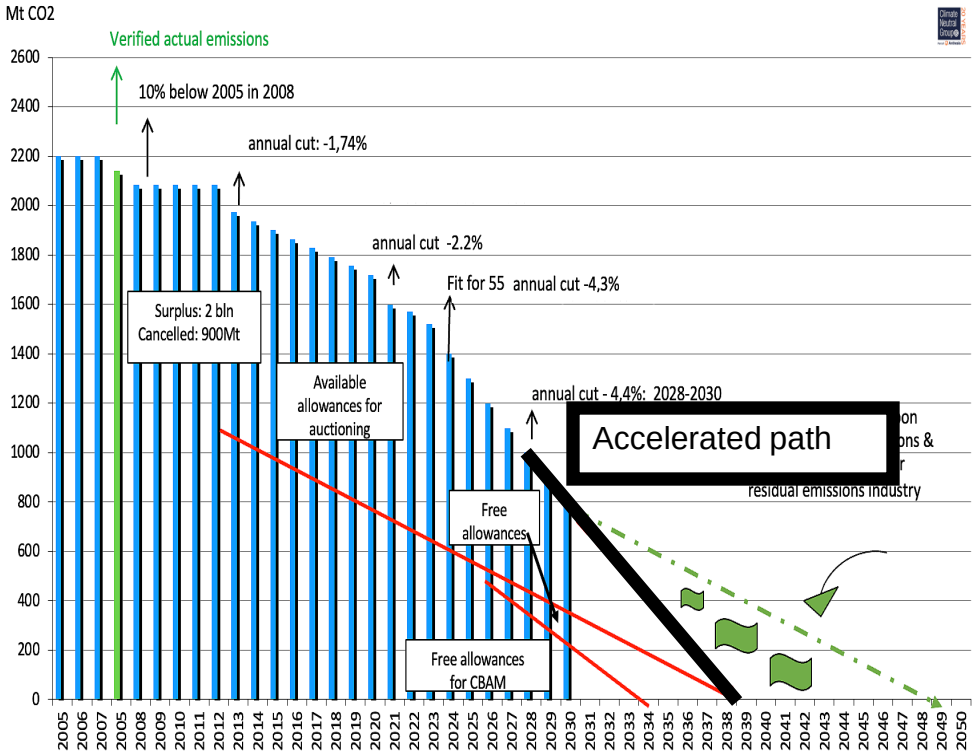


"Linear path" still official EU policy now. However, "accelerated path" to be put into EU law spring 2025

https://www.emissierechten.nl/column/tightening-eu-ets-leads-to-zero-emissions-before-2040/

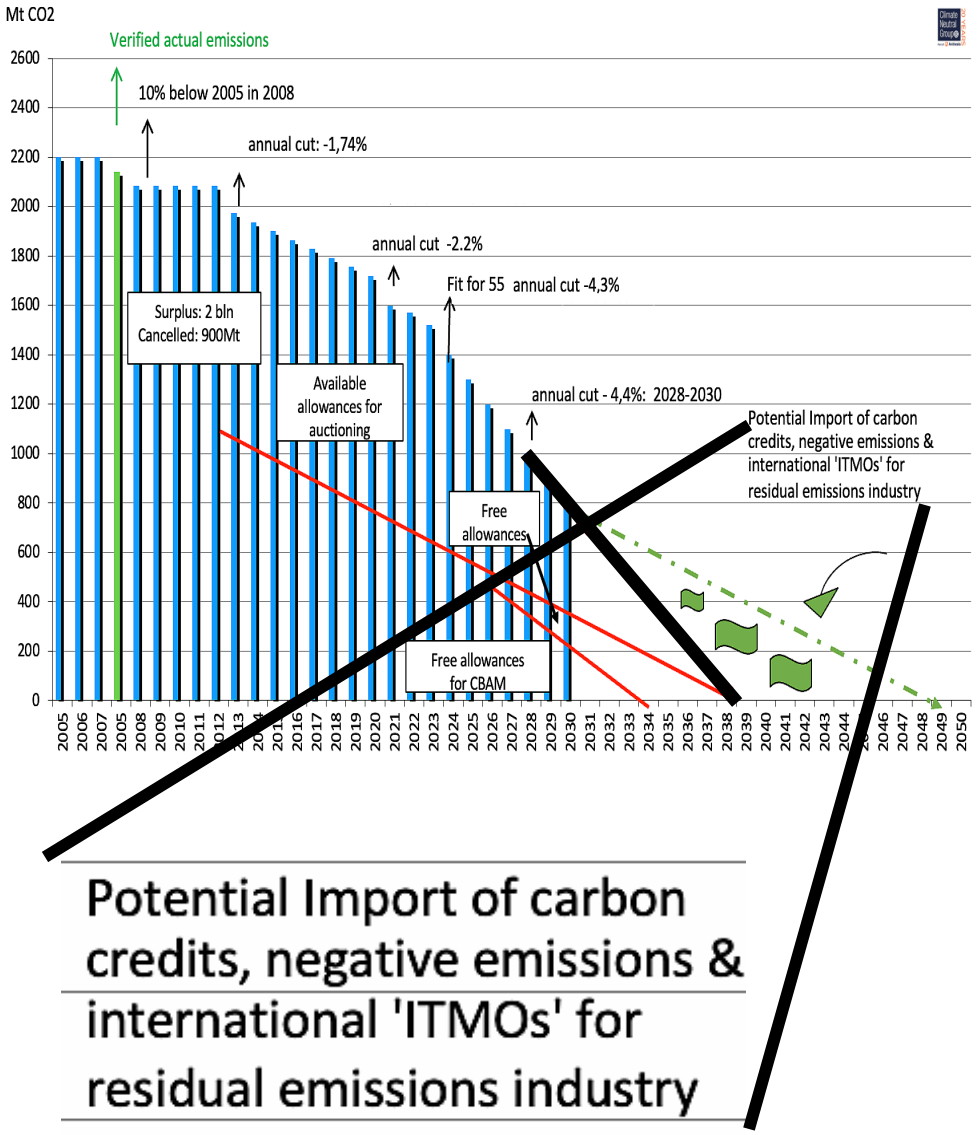
Possible dangers

- Abatement schedules that are too low or too high
  - Accelerated path -> Zero CO2 by 2039???
    - For all industry (including electricity)
    - And aviation & maritime transport
  - What???
  - No coal, natural gas or any industrial emission by 2039?
  - Building a nuclear plant can easily last 14 years
    - CZ & Poland haven't even started yet on nuclears
    - Germany has still coal and new gas plants
      - (green hydrogen plan/fantasy allows gas plants)



Possible dangers

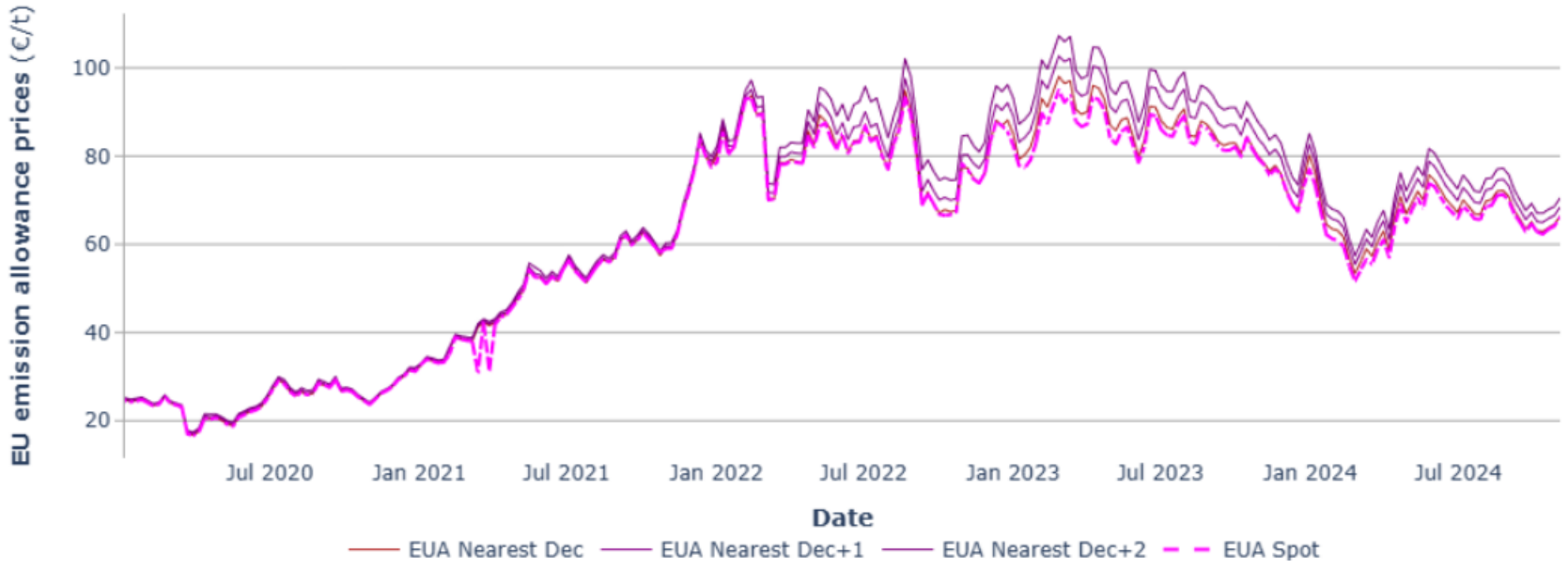
- EU has likely too high abatement schedules!
- Potential political semi-solutions:
  - Buy credits, believe in negative emissions
  - Gives an extra 10 years
- We now see (partial) shift in narrative
  - Energy industry focus from renewables to oil and gas
  - EU governments focus energy & sovereignty security from decarbonization
  - Climate-denying parties getting stronger support in EU



Potential Import of carbon credits, negative emissions & international 'ITMOs' for residual emissions industry

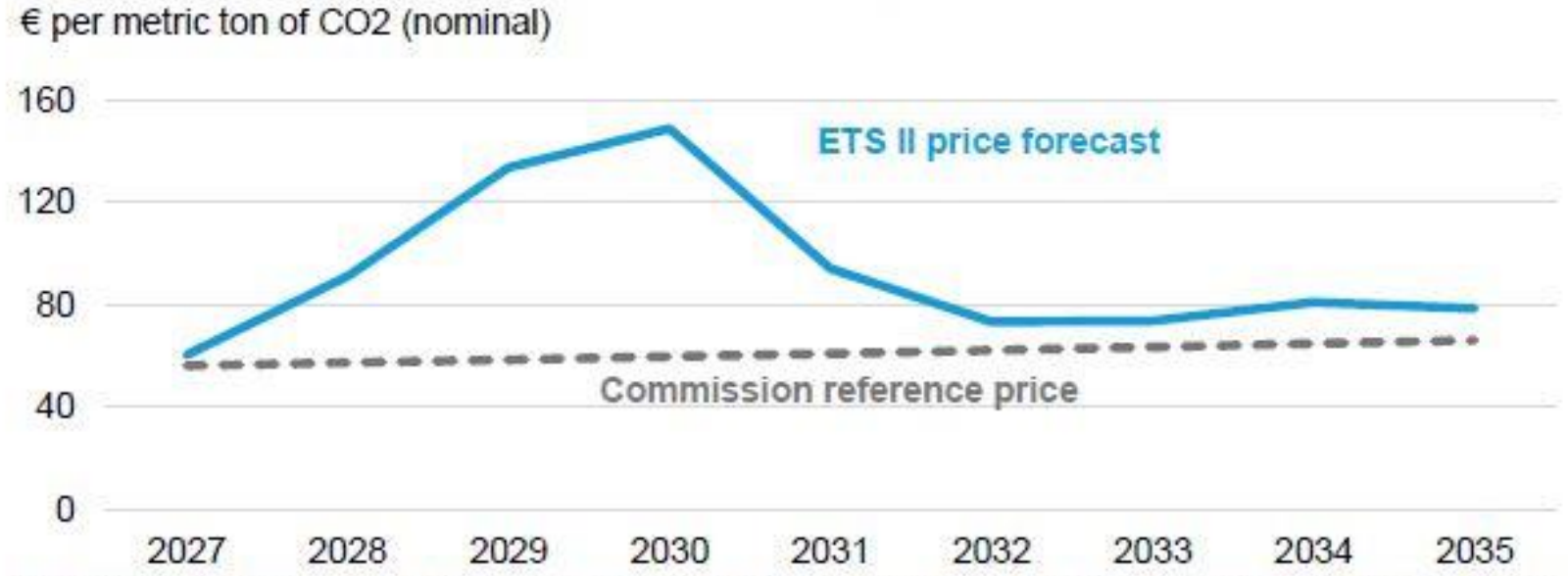
- If I am right to panic about these ETS paths, there should be studies out there that show permit prices jump to astronomical heights, right?

Figure 7 – Evolution of EU emission allowance spot and future prices from 2020



“World’s Highest Carbon Price in 2030 at €149”

Figure 1: Forecast EU ETS II emissions allowance price



Source: BloombergNEF. Note: The reference price is based on €45 per metric ton of CO2 in 2020 that is indexed to consumer price inflation.

Only till 2035

https://about.bnef.com/blog/europes-new-emissions-trading-system-expected-to-have-worlds-highest-carbon-price-in-2030-at-e149-bloombergnef-forecast-reveals/

www.oxfordenergy.org study includes the newest EU plans!

	GHG emissions, $mtCO_{2e}$ (% reduction relative to 1990)			Marginal Abatement (Carbon) Cost*, €/tCO_{2e}		
	2030	2040	2050	2030	2040	2050
Accelerated Path to Net Zero	2,622 (55%)	583 (90%)	0 (100%)	134	17,246	426
Linear Path to Net Zero	2,622 (55%)	1,407 (76%)	0 (100%)	134	420	1,944

Black – input, Red – output

Compare with

Estimates marginal damage carbon

2025	2030	2040	2050
40-100	**45-110**	**54-135**	**66-164**

- I take the 40-100E/tCO2 in 2025 as basis
- Have it increase by an inflation rate of 2%

https://www.oxfordenergy.org/publications/decarbonisation-in-europe-modelling-economic-feasibility-and-the-glidepath-for-gas/
https://climateactiontracker.org/countries/eu/

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Black – input, Red – output

Compare with

Estimates marginal damage carbon

2025	2040	2050	2030
40-100	**54-135**	**66-164**	**45-110**

- This model supports the suspision that the EU ETS path may result in excessively high carbon prices
  - Higher than estimated marginal damage
  - Thus suboptimal (not efficient)
- Such carbon prices likely derail EU economy
  - Thus likely infeasible (economically & politically)

https://www.oxfordenergy.org/publications/decarbonisation-in-europe-modelling-economic-feasibility-and-the-glidepath-for-gas/
https://climateactiontracker.org/countries/eu/

Effect on electricity market & industry

- Permit price increases electricity supply price by
  - Coal: ~1x permit price
  - Gas: ~0.5 x permit price
- Permit price E500/tCO2 (E2000/tCO2)
  - Coal: ~35E/MWh -> 535E/MWh (2035E/MWh)
  - Gas: ~100E/MWh -> 350E/MWh (1100E/MWh)
- If large parts of electricity still generated by coal or gas, prices will explode
  - much worse than in 2022!

- Industry may stop producing
  - But probably before that politicians change course or are voted out

- ETS has drawback that if the abatement path is not well-calibrated, permit prices may skyrocket (or go to zero)
- Carbon taxes might be better suited to balance environmental benefit versus economic costs

- Possible adaptation
- Add a price and a floor ceiling to ETS
  - Borenstein, S., Bushnell, J., & Wolak, F. (2017). California's cap-and-trade market through 2030: A preliminary supply/demand analysis. *Energy Institute at Haas working paper*, *281*.
  - Add a "central bank with permits"
  - Keeps ETS institutions
    - Maintains the policy advantage of difficult to cancel!
  - Price would be kept within a reasonable range
- Likely?
  - This would be a radical break from the 2039~2050 (net) zero target
  - However, ETS has something called "Market Stability Reserve" that could be transformed in such a central bank
    - https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/market-stability-reserve_en

- With a carbon price within damage range (40-100E/tCO2), what abatement can we expect?

Estimates marginal damage carbon

2025 2030

40-100 2040 2050 **45-110**

	GHG emissions, $mtCO_{2e}$ (% reduction relative to 1990)			Marginal Abatement (Carbon) Cost*, €/tCO_{2e}		
	2030	2040	2050	2030	2040	2050
Low Carbon Price	2,793 (52%)	2,285 (61%)	1,878 (68%)	68	91	114
Accelerated Path to Net Zero	2,622 (55%)	583 (90%)	0 (100%)			
Linear Path to Net Zero	2,622 (55%)	1,407 (76%)	0 (100%)			

Very reasonable carbon prices!

Black – input, Red – output

- Abatement path that maximizes welfare reaches 61% in 2040 and 68% in 2050
  - Assuming the OIER model is correct and that marginal carbon damage in range 40-100 and growing with 2~3% annually
- **<u>Implies EU not climate neutral by 2050</u>**

https://www.oxfordenergy.org/publications/decarbonisation-in-europe-modelling-economic-feasibility-and-the-glidepath-for-gas/
https://climateactiontracker.org/countries/eu/

Conclusion

- Physically impossible targets are seldom implemented
  - Copenhagen & New Zealand (Helsinki?) teach important lesson
- EU ETS targets are rigid and likely not set correctly
  - Past ones were too low
  - Future ones are likely *much* too high
  - Expect relaxing of targets over time (and complaining)
  - Optimal abatement may be 68% in 2050 (instead of 100%)
    - Of course, if EU's very optimistic assumptions come true, optimal abatement will be much more than 68%
    - EU's 2020 promise of carbon neutral in 2050 most likely not welfare-optimizing
      - Not a bad goal, but should not be pursued at any cost
- Carbon taxes would be less rigid
  - Better balance of economic cost and environmental benefits
  - Adding price ceilings (and price floors) to ETS would be a useful hybrid solution
  - Market Stability Fund may be turned into a carbon permit central bank

- Possible dangers
  - Carbon price floors that are too low or too high
    - NL: 125 E/tCO2
    - Sweden: 127 $/tCO2
    - Norway: 107 $/tCO2
    - Switzerland: 132 $/tCO2
    - Argentina 0.81$/tCO2

https://carbonpricingdashboard.worldbank.org/compliance/instrument-detail

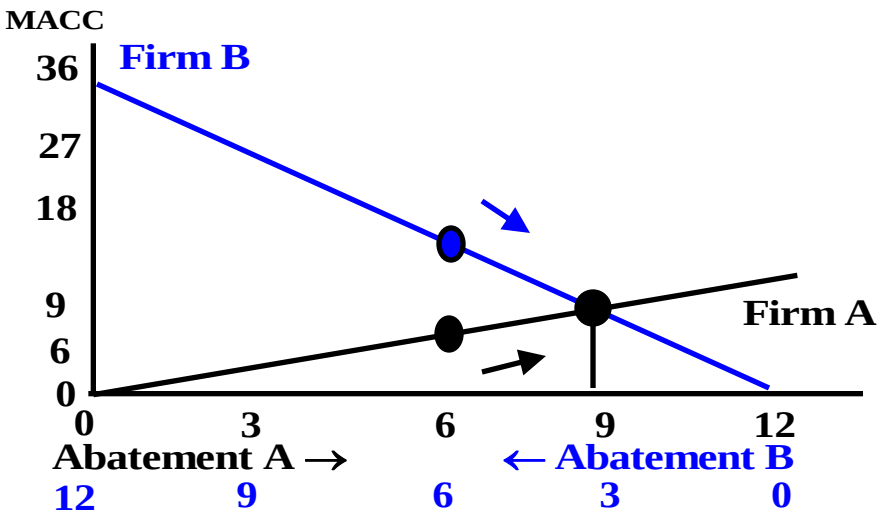
- Possible dangers
  - EU abatement schedules and progress indicate a (very high?) risk of being too ambitious
  - EU Carbon price floors used indicate a high risk of being too high

Carbon taxes concretely

- What should be the global carbon tax in $?
  - $40~$100/ton CO2
  - increase with 2% a year (inflation correction)
- So maximum for traveling 1000km:
  - For car:
    - ~$14 for car (for the whole car)
      - ~0.2 kg/km = 0.2 ton/1000km -> $8~$20
  - For plane:
    - ~$14 taking plane (per person)
      - ~0.2 kg/km = 0.2ton/1000km -> $8~$20
  - **But, you would pay only about 40%~75% of this in LT!**
    - Because industry will start to make transport less polluting
    - low-emission technologies will replace high-emission ones
- Numbers are somewhat sensitive about assumptions of type of car/plane, how many people in the car/plane, how high the plane flies, etc…

Conclusion

- The number of countries putting a price on CO2 is increasing
  - Either by tax, ETS or both
- However, the price is mostly wrong
  - Too low, sometimes far too low (<$2)
  - In a few individual cases too high ($137)
  - EU plans for astronomically high price!
- **Most visible source of efficiency loss due to:**
  - Too high price in EU in near future!
  - Only part of emitting activities taxed
  - Different carbon prices



- Efficiency requires that the marginal abatement cost is the same
  - In all countries
  - Over all activities in each country
    - Producing electricity
    - Driving a car
    - Agricultural activities (breeding cows for beef)

- A tax in the range $40-$100/Ton would affect costs, but not dramatically
  - Planes more than (full) car drives

- EU impact assessment uses extraordinarily optimistic assumptions regarding
  1. Green hydrogen
  2. CCS
  3. Renewables upscaling

1. Green Hydrogen:EU strategy (2020)

2025

- **6 GW** of electrolysers powered by renewable electricity
- Replace existing **hydrogen production**
- Regulation for liquid hydrogen markets
- Planning of hydrogen infrastructure

2030

- **40 GW** of electrolysers powered by renewable electricity
- New applications in **steel and heavy duty, long distance and aviation and maritime transport**
- Hydrogen for electricity balancing purposes
- Creation of “Hydrogen Valleys”
- Cross-border logistical infrastructure

2050

- Scale-up to **all hard-to-decarbonise sectors**
- Expansion of hydrogen-derived **synthetic fuels**
- EU-wide infrastructure network
- An open international market with € as benchmark

- Source: Hydrogen Europe
  - 2024 Sept: **385 MW**
  - https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/water-electrolysis-and-hydrogen-growing-deployment-prospects-europe-and-beyond-2023-11-24_en
- **1 year for another 5 615 MW**
  - **To get to 6GW (x16) in 2025**
    - Apparently the industrial capacity exist to build this (8.7GW)?
- **6 years for another 39 615MW**
  - **To get to 40GW (x104) in 2030**

- **EU is drastically behind schedule**
  - **Not catching up implies that the present (“linear” & “accelerated”) EU ETS plans may indeed be disastrous**

2. CCS: EU Strategy

- CCS is still in its infancy
- In EU, 4.6 MtCO2/y under construction
- Need
  - 2030: 50 (x11)
  - 2040: 280 (x61)
  - 2050: 450

- Cost estimates E150-E350/tCO2
  - High
  - But if they are accurate and don't increase over time, then some CCS may make (limited) sense after 2040 (from a cost-benefit point of view)

3. Renewables

- “Renewables history”
  - EU has managed to increase the amount of renewables in its system considerably
  - But at inefficiently high costs
    - > $200/TCO2 (often much higher)
    - > social cost of CO2 ($40~$100/TCO2)
    - > EUAs
      - permit prices of EU ETS
  - Governments, EU not excluded, struggle to implement decarbonization effort in cost-efficient manner.

3. Renewables

- Intermittency & self-cannibalization
  - EU Solar producers earn almost nothing in the coming years (except subsidies)
  - Self-cannibalizing of solar due to high positive production correlation.
  - Similar for wind

Correlation matrix in hourly resolution (2020-2022)

	Wind-DEU	Wind-FRA	Wind-BEL	Wind-NOR	Wind-SWE	Wind-GBR	Wind-ESP	Solar-DEU	Solar-FRA	Solar-BEL	Solar-GBR	Solar-ESP	Demand-DEU	Demand-FRA	Demand-BEL	Demand-NOR	Demand-SWE	Demand-GBR	Demand-ESP
Wind-DEU	1	0.58	0.67	0.33	0.37	0.59	0.12												
Wind-FRA	0.58	1	0.73	0.26	0.16	0.49	0.36												
Wind-BEL	0.67	0.73	1	0.29	0.16	0.72	0.17												
Wind-NOR	0.33	0.26	0.29	1	0.55	0.33	0.19												
Wind-SWE	0.37	0.16	0.16	0.55	1	0.23	0.02												
Wind-GBR	0.59	0.49	0.72	0.33	0.23	1	0.15												
Wind-ESP	0.12	0.36	0.17	0.19	0.02	0.15	1												
Solar-DEU	-0.2	-0.19	-0.18	-0.15	-0.15	-0.17	-0.24	1	0.89	0.92	0.82	0.77							
Solar-FRA	-0.14	-0.16	-0.14	-0.11	-0.13	-0.12	-0.23	0.89	1	0.89	0.86	0.89							
Solar-BEL	-0.19	-0.19	-0.2	-0.15	-0.15	-0.18	-0.22	0.92	0.89	1	0.86	0.77							
Solar-GBR	-0.13	-0.13	-0.15	-0.14	-0.14	-0.17	-0.17	0.82	0.86	0.86	1	0.8							
Solar-ESP	-0.12	-0.11	-0.09	-0.13	-0.19	-0.1	-0.19	0.77	0.89	0.77	0.8	1							
Demand-DEU	0.15	0.13	0.14	0.15	0.04	0.16	0.06	0.29	0.36	0.28	0.28	0.37	1	0.66	0.9	0.56	0.67	0.75	0.8
Demand-FRA	0.25	0.26	0.2	0.29	0.18	0.3	0.32	-0.11	-0.03	-0.1	-0.1	-0.05	0.66	1	0.81	0.87	0.87	0.78	0.6
Demand-BEL	0.11	0.13	0.1	0.16	0.05	0.16	0.17	0.08	0.16	0.05	0.08	0.19	0.9	0.81	1	0.7	0.77	0.86	0.78
Demand-NOR	0.32	0.36	0.29	0.29	0.21	0.37	0.36	-0.16	-0.08	-0.14	-0.13	-0.11	0.56	0.87	0.7	1	0.97	0.7	0.39
Demand-SWE	0.29	0.34	0.27	0.27	0.17	0.35	0.32	-0.08	-0.01	-0.08	-0.06	-0.03	0.67	0.87	0.77	0.97	1	0.75	0.46
Demand-GBR	0.13	0.17	0.11	0.18	0.1	0.14	0.24	-0.06	0.05	-0.06	-0.05	0.11	0.75	0.78	0.86	0.7	0.75	1	0.74
Demand-ESP	0.04	0.05	0.04	0.04	-0.04	0.07	0.05	0.27	0.35	0.26	0.27	0.36	0.8	0.6	0.78	0.39	0.46	0.74	1

Correlation matrix in hourly resolution (2020-2022)

	Wind-DEU	Wind-FRA	Wind-BEL	Wind-NOR	Wind-SWE	Wind-GBR	Wind-ESP	Solar-DEU	Solar-FRA	Solar-BEL	Solar-GBR	Solar-ESP	Demand-DEU	Demand-FRA	Demand-BEL	Demand-NOR	Demand-SWE	Demand-GBR	Demand-ESP
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Demand-NOR	0.32	0.36	0.29	0.29	0.21	0.37	0.36	-0.16	-0.08	-0.14	-0.13	-0.11	0.56	0.87	0.7	1	0.97	0.7	0.39
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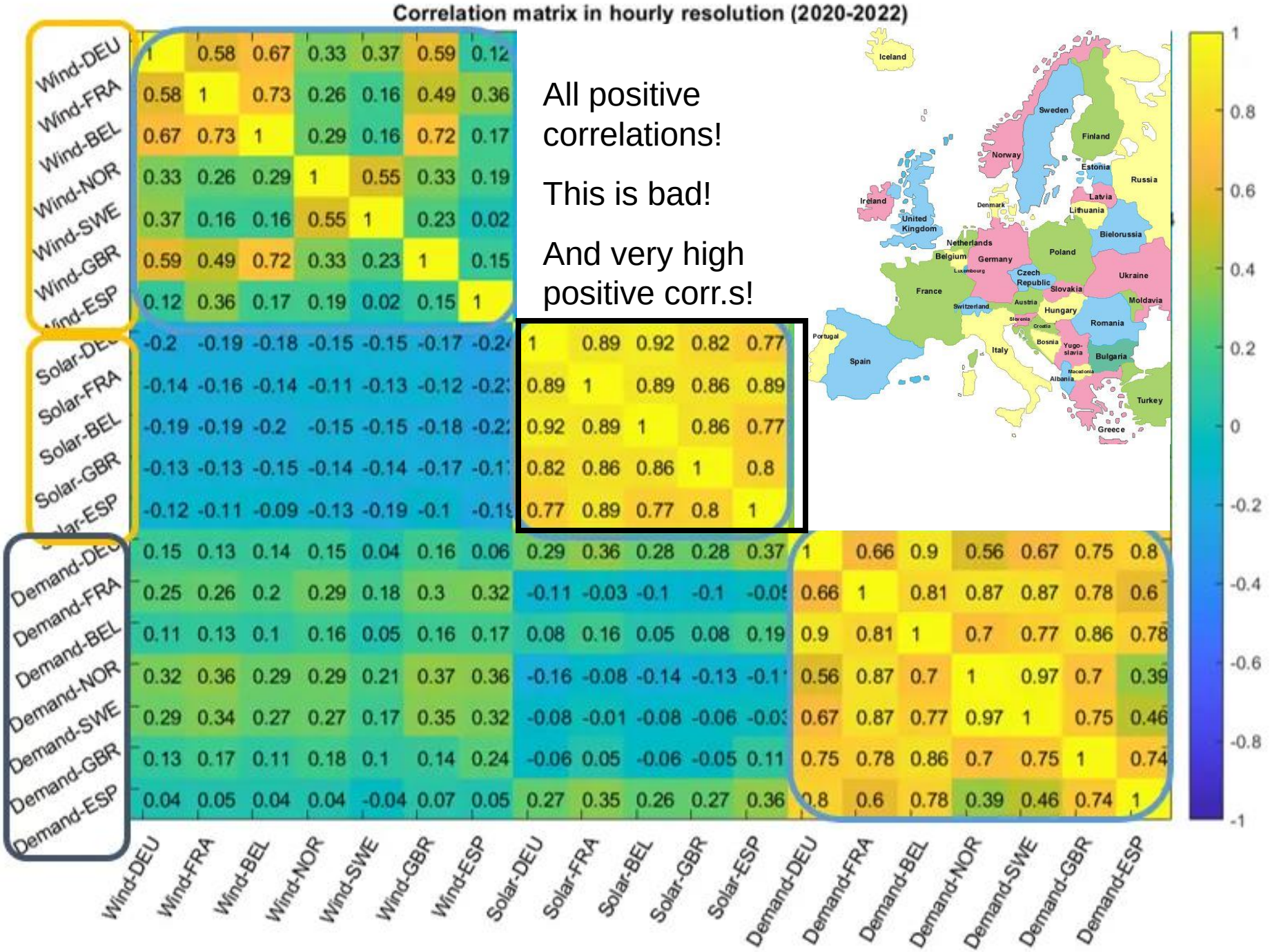
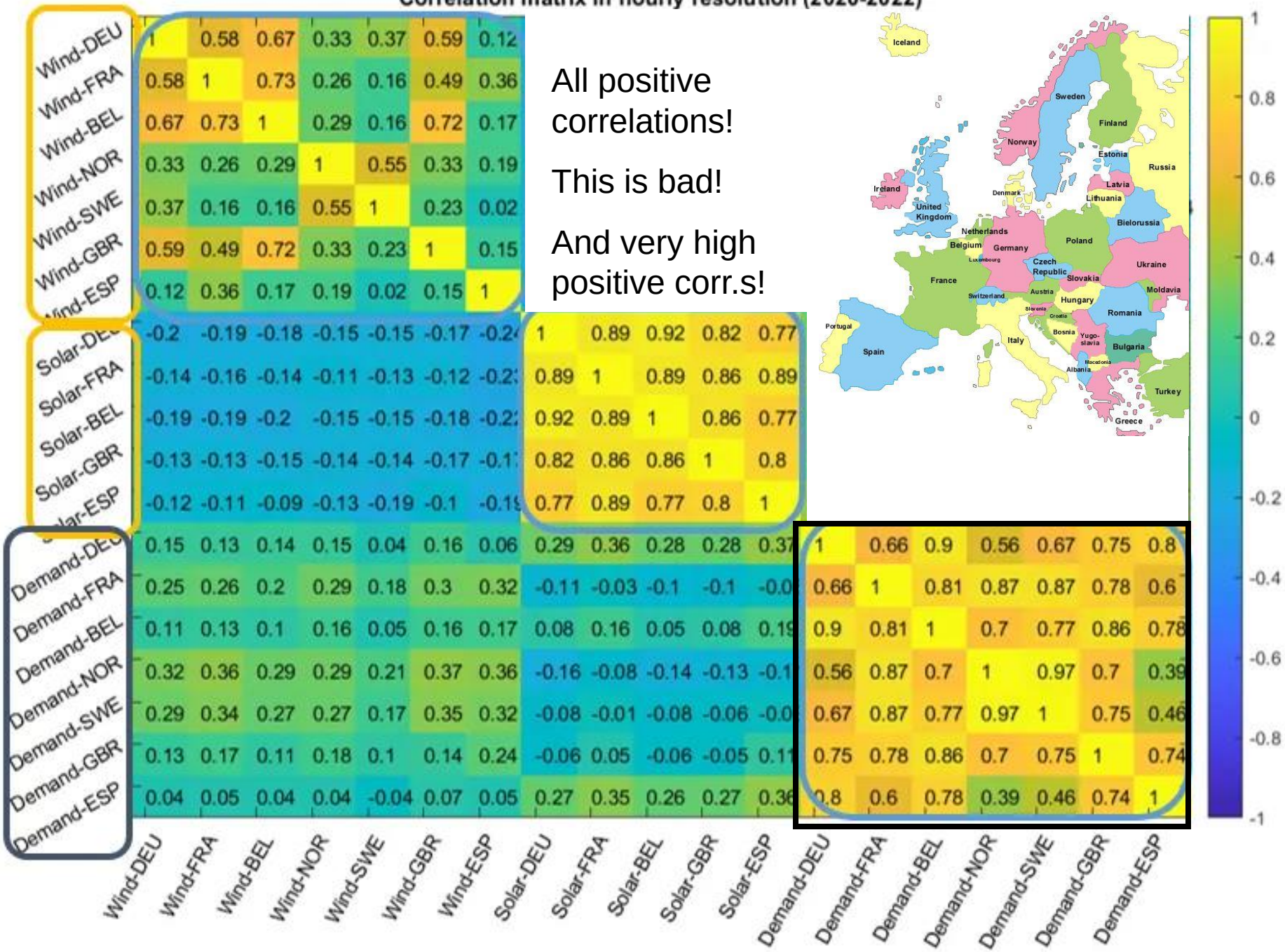
Demand-ESP	0.04	0.05	0.04	0.04	-0.04	0.07	0.05	0.27	0.35	0.26	0.27	0.36	0.8	0.6	0.78	0.39	0.46	0.74	1

All positive correlations!

This is bad!


Correlation matrix in hourly resolution (2020-2022)
All positive correlations!
This is bad!
And very high positive corr.s!
Wind-DEU
Wind-FRA
Wind-BEL
Wind-NOR
Wind-SWE
Wind-GBR
Wind-ESP
Solar-DEU
Solar-FRA
Solar-BEL
Solar-GBR
Solar-ESP
Demand-DEU
Demand-FRA
Demand-BEL
Demand-NOR
Demand-SWE
Demand-GBR
Demand-ESP
Iceland
Sweden
Finland
Norway
Estonia
Russia
Ireland
Latvia
Denmark
Lithuania
United Kingdom
Belorussia
Netherlands
Poland
Belgium
Germany
Luxembourg
Czech Republic
Ukraine
France
Slovakia
Switzerland
Austria
Moldavia
Hungary
Slovenia
Croatia
Romania
Portugal
Bosnia
Yugo-slavia
Italy
Bulgaria
Spain
Macedonia
Albania
Turkey
Greece
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

Correlation matrix in hourly resolution (2020-2022)



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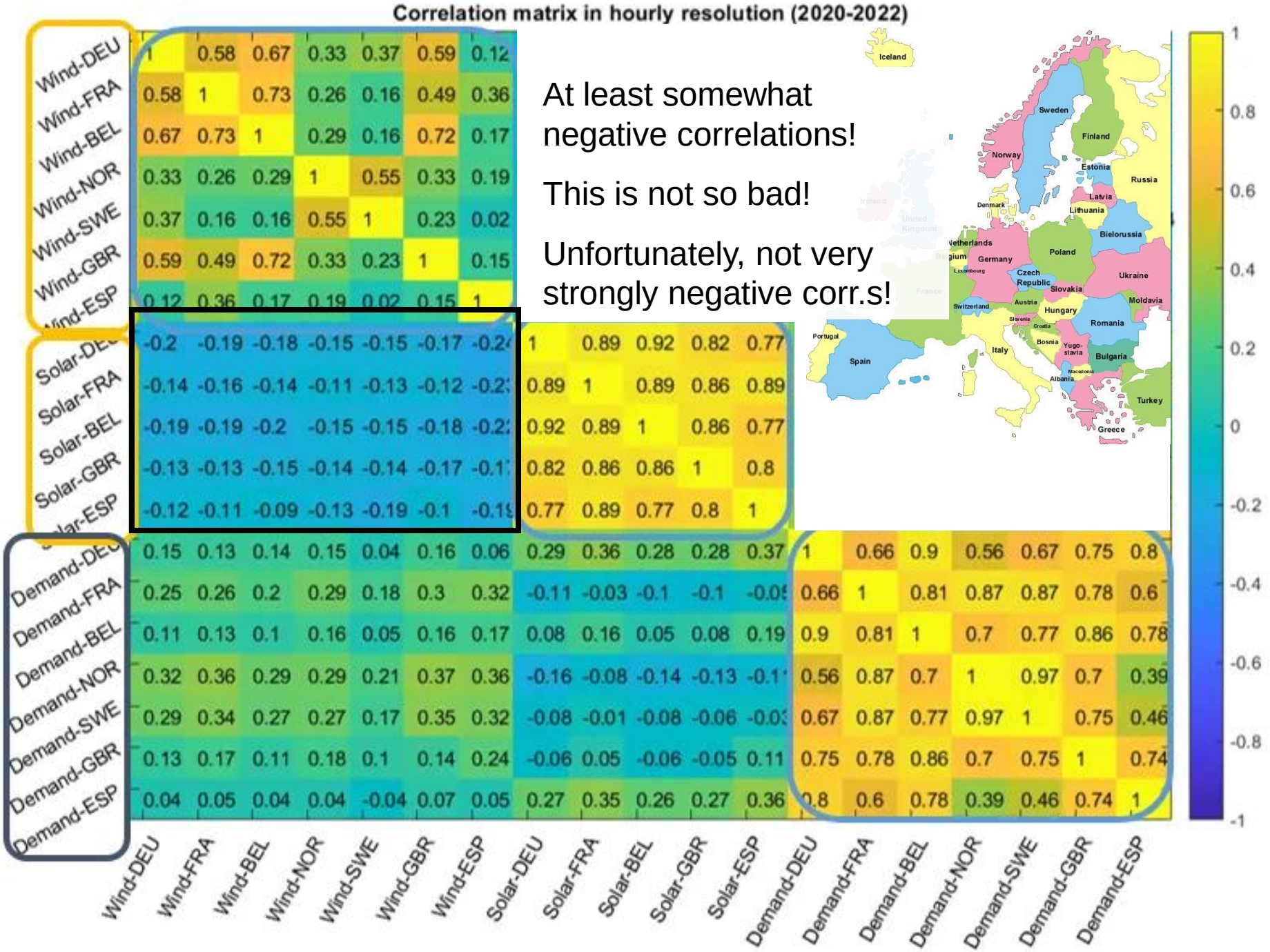
Correlation matrix in hourly resolution (2020-2022)
Wind-DEU
Wind-FRA
Wind-BEL
Wind-NOR
Wind-SWE
Wind-GBR
Wind-ESP
Solar-DEU
Solar-FRA
Solar-BEL
Solar-GBR
Demand-DEU
Demand-FRA
Demand-BEL
Demand-NOR
Demand-SWE
Demand-GBR
Demand-ESP
At least somewhat negative correlations!
This is not so bad!
Unfortunately, not very strongly negative corr.s!
Iceland
Sweden
Finland
Norway
Estonia
Russia
Latvia
Lithuania
Denmark
Ireland
United Kingdom
Netherlands
Belgium
Germany
Luxembourg
Poland
Bielorussia
Czech Republic
Slovakia
Ukraine
France
Switzerland
Austria
Hungary
Moldavia
Slovenia
Croatia
Romania
Portugal
Spain
Italy
Bosnia
Yugo-slavia
Bulgaria
Macedonia
Albania
Turkey
Greece
1
0.8
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0.4
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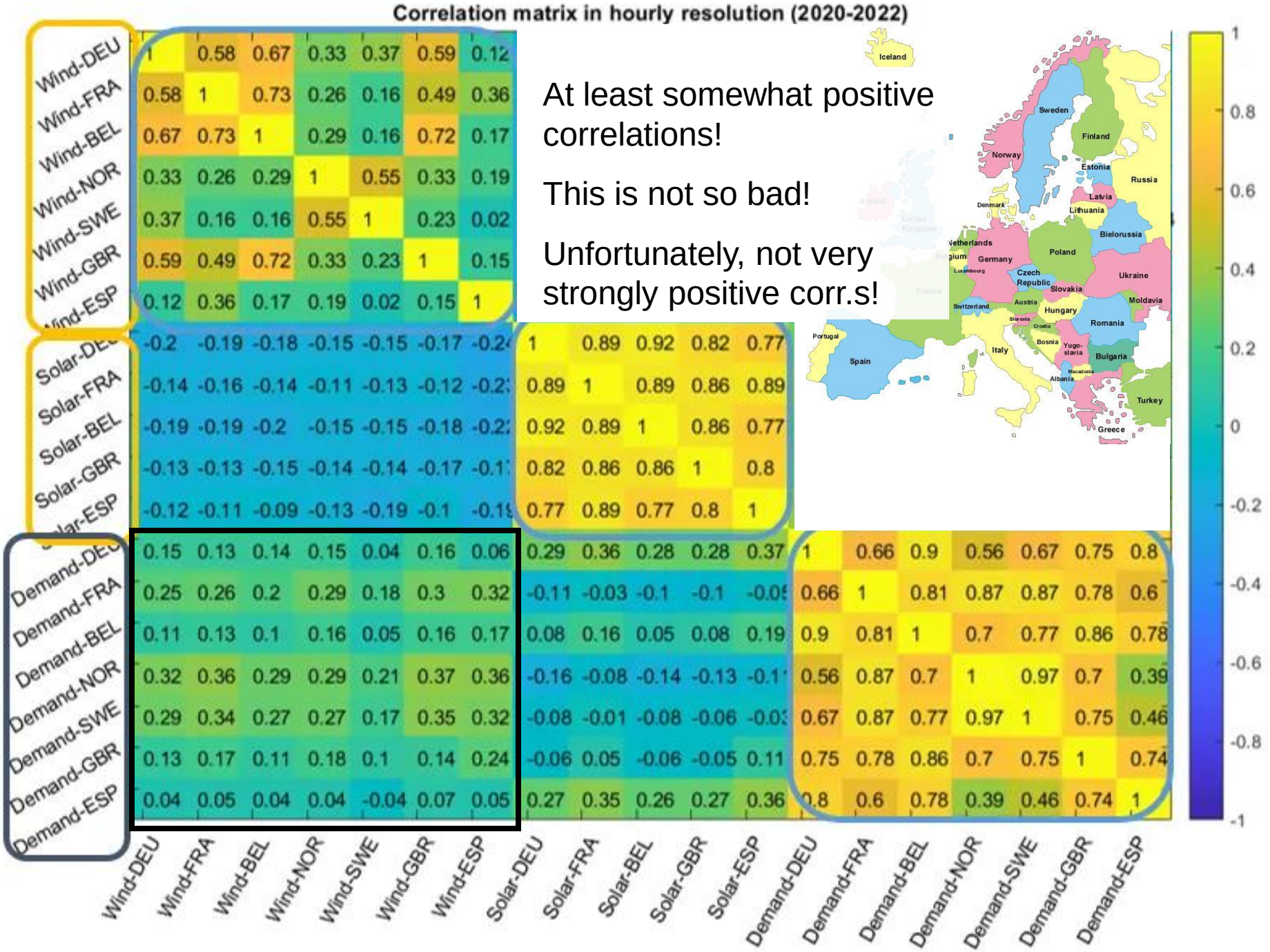
0
-0.2
-0.4
-0.6
-0.8
-1


Correlation matrix in hourly resolution (2020-2022)
Wind-DEU
Wind-FRA
Wind-BEL
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Solar-DEU
Solar-FRA
Solar-BEL
Solar-GBR
Solar-ESP
Demand-DEU
Demand-FRA
Demand-BEL
Demand-NOR
Demand-SWE
Demand-GBR
Demand-ESP
1 0.58 0.67 0.33 0.37 0.59 0.12
0.58 1 0.73 0.26 0.16 0.49 0.36
0.67 0.73 1 0.29 0.16 0.72 0.17
0.33 0.26 0.29 1 0.55 0.33 0.19
0.37 0.16 0.16 0.55 1 0.23 0.02
0.59 0.49 0.72 0.33 0.23 1 0.15
0.12 0.36 0.17 0.19 0.02 0.15 1
-0.2 -0.19 -0.18 -0.15 -0.15 -0.17 -0.2
-0.14 -0.16 -0.14 -0.11 -0.13 -0.12 -0.2
-0.19 -0.19 -0.2 -0.15 -0.15 -0.18 -0.2
-0.13 -0.13 -0.15 -0.14 -0.14 -0.17 -0.1
-0.12 -0.11 -0.09 -0.13 -0.19 -0.1 -0.1
1 0.89 0.92 0.82 0.77
0.89 1 0.89 0.86 0.89
0.92 0.89 1 0.86 0.77
0.82 0.86 0.86 1 0.8
0.77 0.89 0.77 0.8 1
0.15 0.13 0.14 0.15 0.04 0.16 0.06
0.25 0.26 0.2 0.29 0.18 0.3 0.32
0.11 0.13 0.1 0.16 0.05 0.16 0.17
0.32 0.36 0.29 0.29 0.21 0.37 0.36
0.29 0.34 0.27 0.27 0.17 0.35 0.32
0.13 0.17 0.11 0.18 0.1 0.14 0.24
0.04 0.05 0.04 0.04 -0.04 0.07 0.05
0.29 0.36 0.28 0.28 0.37
-0.11 -0.03 -0.1 -0.1 -0.0
0.08 0.16 0.05 0.08 0.19
-0.16 -0.08 -0.14 -0.13 -0.1
-0.08 -0.01 -0.08 -0.06 -0.0
-0.06 0.05 -0.06 -0.05 0.11
0.27 0.35 0.26 0.27 0.36
1 0.66 0.9 0.56 0.67 0.75 0.8
0.66 1 0.81 0.87 0.87 0.78 0.6
0.9 0.81 1 0.7 0.77 0.86 0.78
0.56 0.87 0.7 1 0.97 0.7 0.39
0.67 0.87 0.77 0.97 1 0.75 0.46
0.75 0.78 0.86 0.7 0.75 1 0.74
0.8 0.6 0.78 0.39 0.46 0.74 1
1
0.8
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-1
At least somewhat positive correlations!
This is not so bad!
Unfortunately, not very strongly positive corr.s!
Iceland
Sweden
Finland
Norway
Estonia
Russia
Latvia
Denmark
Lithuania
Ireland
United Kingdom
Netherlands
Belgium
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Luxembourg
Czech Republic
Slovakia
Ukraine
France
Switzerland
Austria
Moldavia
Hungary
Slovenia
Croatia
Romania
Portugal
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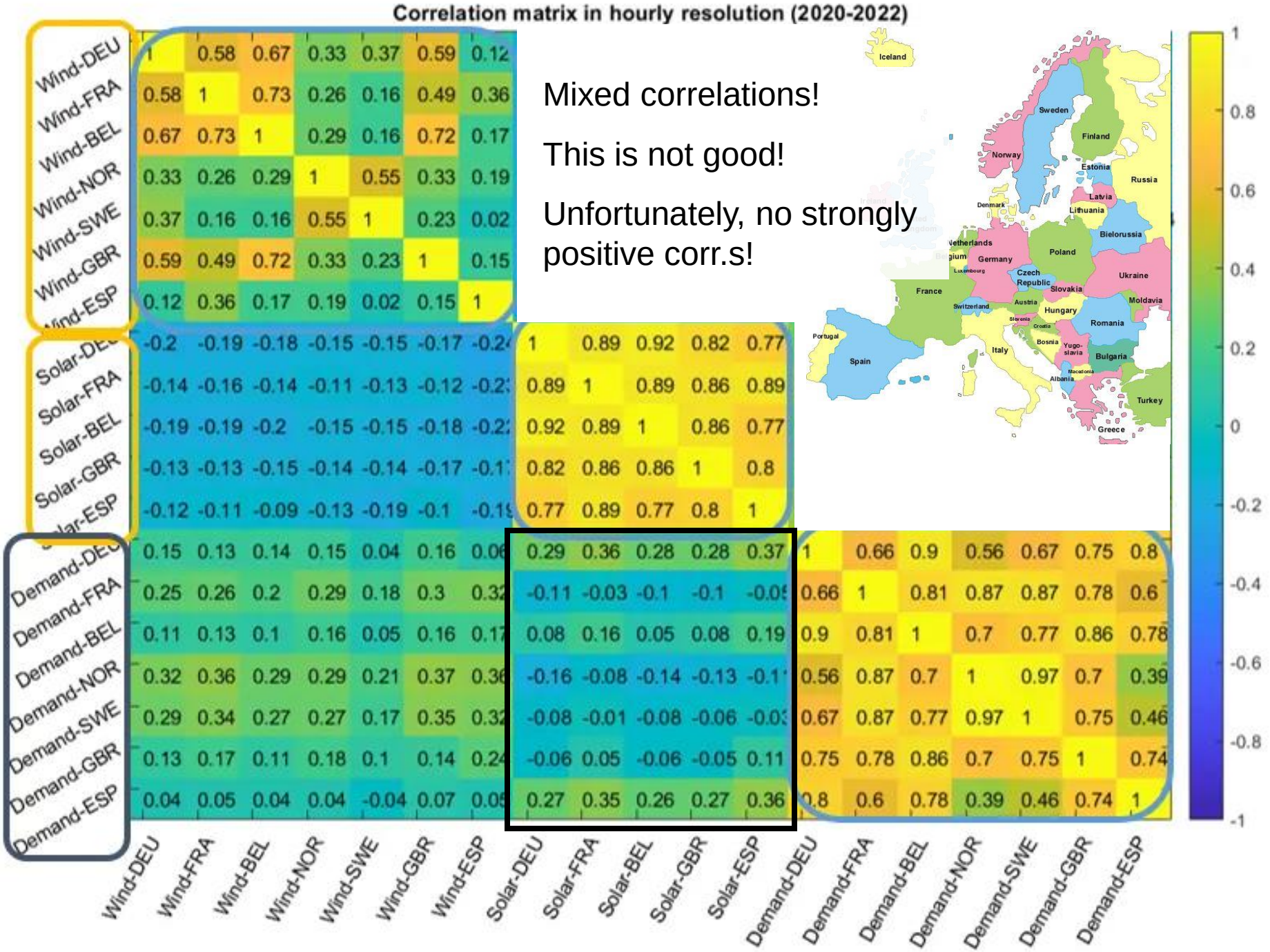
Yugo-slavia
Italy
Bulgaria
Spain
Macedonia
Albania
Turkey
Greece


Correlation matrix in hourly resolution (2020-2022)
Mixed correlations!
This is not good!
Unfortunately, no strongly positive corr.s!
Wind-DEU
Wind-FRA
Wind-BEL
Wind-NOR
Wind-SWE
Wind-GBR
Wind-ESP
Solar-DEU
Solar-FRA
Solar-BEL
Solar-GBR
Solar-ESP
Demand-DEU
Demand-FRA
Demand-BEL
Demand-NOR
Demand-SWE
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Iceland
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Switzerland
Austria
Moldavia
Hungary
Romania
Portugal
Spain
Italy
Bosnia
Yugo-slavia
Bulgaria
Albania
Turkey
Greece

- Carbon pricing is a very powerful measure
- Can reduce carbon emissions effectively and (close to) as cheap as possible
- But
  - Requires wise handling of carbon pricing revenue
    - (no Saudi-Arabian neom or “line”)
  - Requires setting the target right
    - Should reflect the marginal damage of carbon
    - EU set target too low in past
    - EU’s plans set target astronomically high
      - This may politically destroy the ETS