Implementing the Kyoto Protocol and beyond:
An application of GTAP-E

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Outline

- ***Question***: What are the economic implications of implementing Kyoto protocol commitments for greenhouse gas emission reductions?
  - Three scenarios, to capture Kyoto flexibility mechanisms
    - Annex I (developed) countries meet commitments with no trading
    - Trading within Annex I only (allowance trading, Joint Implementation)
    - Trading throughout the world (~ Clean Development Mechanism)
- **Tool:** new features in GTAP_E
- **In-depth discussions**:
  - Emissions trading: global welfare implications
  - Economic structure and costs of abatement: US case
  - Non-Annex I countries and leakage
  - Implications of coal-emission-intensity technical change

GTAP_E: New features

- ***Motivation***: Energy combustion generates ~80% of GHG global emissions
- GTAP_E production structure:
  - GTAP_E includes emissions from energy inputs (coal, oil, gas, petroleum products)
  - Substitution among fuels in producing energy; substitution between energy and capital in a new endowment aggregate
- Bottom line: mitigation can be achieved by input substitution (inter-fuel and energy vs. capital) as well as by output contraction

Context: Kyoto emissions trading

		Kyoto % chg from 1990	quota % chge from 2001	emissions hares in 2001	emission intensity
	1 USA	-7%	-36%	24%	0.19
	2 EU	-8%	-22%	15%	0.11
	3 EEFSU	-4%	5%	13%	0.88
	4 JPN	-6%	-32%	5%	0.08
	5 RoA1		-36%	4%	0.17
Annex I		**-5%**	**-24%**	**61%**	**0.17**
	6 EEx	-	-	**11%**	0.29
	7 CHIND	-	-	18%	0.86
	8 RoW	-	-	10%	0.22
Non-Annex I		-	-	**39%**	**0.37**
All countries		-		**100%**	

Context for Kyoto emissions quotas

- Kyoto reductions from 1990 averaged -5%
- Reduction commitments restated to account for emission increase from 1990 to 2001
- Level of emissions highest in US (25%)
- Emission intensity of production highest:
  - In EEFSU and India/China
  - On average, Annex I lower than non-Annex I

Emissions trading: global welfare implications

The broader the trading group…

…the lower the marginal abatement cost of meeting fixed level of global emission reductions

- No trade: highly variable MAC across regions
- Annex I trading: permit price = $77/ton
  - Exception: in no-trade, quota not binding for Annex I EEFSU => MAC = 0; EEFSU decreases emissions to sell permits to all Annex I so MAC increases to $77/ton
- Global trading: permit price = $29/ton

The broader the trading group…

…the closer total global emissions reductions are to reduction commitments – if capped sectors have binding constraints

- Trading reduces leakage from uncapped regions with:
  - Lower MAC => lesser downward price effect on energy resources and energy-intensive goods, therefore less increase in output in unregulated regions
  - Uncapped countries are internalizing the carbon price

  (Leakage issue discussed by group 2)
- *Exception*: “hot air” of EEFSU due to lack of binding Annex I emission reduction commitment in Experiment 2
  - To sell permits, EEFSU decreases emissions, but total Annex I emissions increase due to purchase of its “hot air” (38MMT CO2)

Regional changes in emissions, MAC

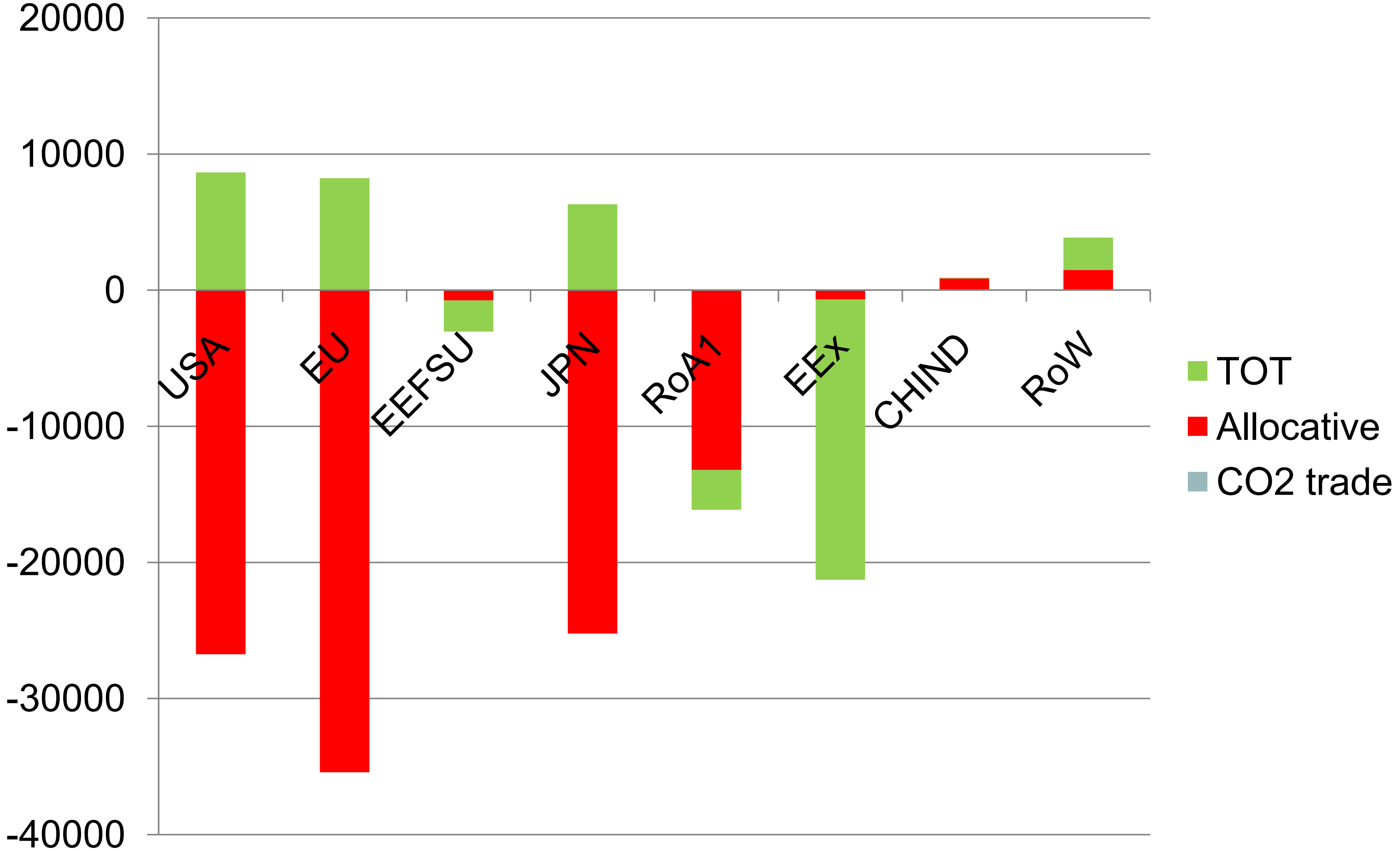
		No trading			Annex I trading			Global trading	
Regions		% chg emission	Marginal abatemt cost		% chg emission	Marginal abatemt cost		% chg emission	Marginal abatemt cost
	1 USA	-35.6%	$128		-26.3	$77		-12.3%	$29
	2 EU	-22.4%	$141		-14.3	$77		-5.9%	$29
	3 EEFSU	4.9%	$0		-26.6	$75		-12.8%	$29
	4 JPN	-31.8%	$226		-15.5	$77		-6.4%	$29
	5 RoA1	-35.7%	$173		-21.0	$77		-9.2%	$29
Annex I total		**-23.8%**			**-22.1**	**$77**		**-10.1%**	**$29**
	6 EEx	3.6%	$0		2.7	$0		-7.2%	$29
	7 CHIND	1.5%	$0		1.1	$0		-32.6%	$29
	8 RoW	4.3%	$0		3.6	$0		-8.5%	$29
Non-Annex I total		**2.8%**			**2.2**	**$0**		**-19.0%**	**$29**
All countries		**-13.5%**			**-12.7**			**-13.6**	
Total chg emissions		**-832**			**-784**			**-837**	

Effects of model design features on marginal abatement costs (MAC)

- Are elasticities of substitution (inter-fuel, energy-capital) may be overstated? If so:
  - $\Rightarrow$ Annex I: emissions reduction overstated, MAC understated
  - $\Rightarrow$ Non-Annex I: leakage understated
  - – reducing global leakage: group 2
  - – *Global trading scenario*: CDM trading overstated, CDM leakage not captured due to only reductions priced (not increases)
- Model excludes non-energy mitigation options:
  - => Inclusion of ag and forestry options (land use change, fertilizer, livestock) would reduce MAC

Welfare Decomposition

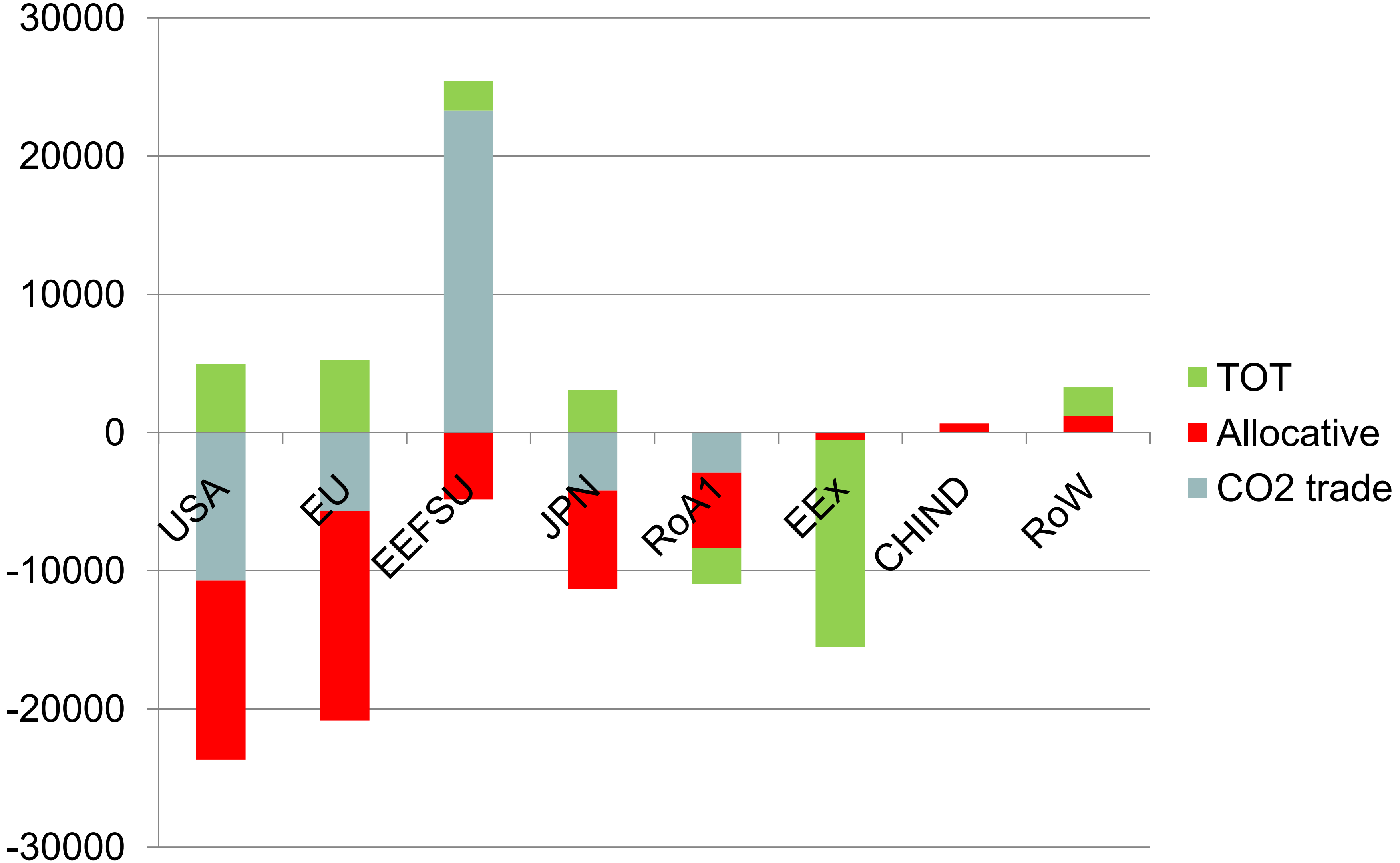
No Trade


20000
10000
0
-10000
-20000
-30000
-40000
USA
EU
EEFSU
JPN
RoA1
EEx
CHIND
RoW
TOT
Allocative
CO2 trade

Key Welfare Impacts

- EVs for Annex 1 countries fall
  - reduction in allocative efficiency
  - partly recovered by TOT improvement (US, EU, Japan)
- TOT for RoA1 and EEx falls
  - world price reduction
- EEFSU also worse off in scenario 1 (no trade)

Annex 1 Trade



World Trade


30000
20000
10000
0
-10000
-20000
-30000
USA
EU
EEFSU
JPN
RoA1
EEx
CHIND
RoW
TOT
Allocative
CO2 trade

Key Welfare Impacts (cont')

- Aggregate EV loss reduces:

  -100bn → -45bn → -19bn

  (No trade) (Annex 1) (World)

- EEFSU better off with Annex 1 trade
  - TOT effect
- World trade generates higher welfare gain for China, India and RoW

Key Welfare Impacts

- EVs for Annex 1 countries fall
- TOT for RoA1 and EEx falls
- EEFSU worse off in scenario 1
- Aggregate EV loss reduces
- EEFSU better off with Annex 1 trade
- China and India gain with world trade

Economic structure and costs of abatement: US case

Structural Effects on Marginal Cost of Abatement

Questions:

-As emission quota becomes more strict, what happens to MAC?

- Why do some countries have higher MAC?

Hypothesis:

- The lower emission quota, the higher MAC
- MAC represent the tax rate of emission, then cheaper abatement options are used first

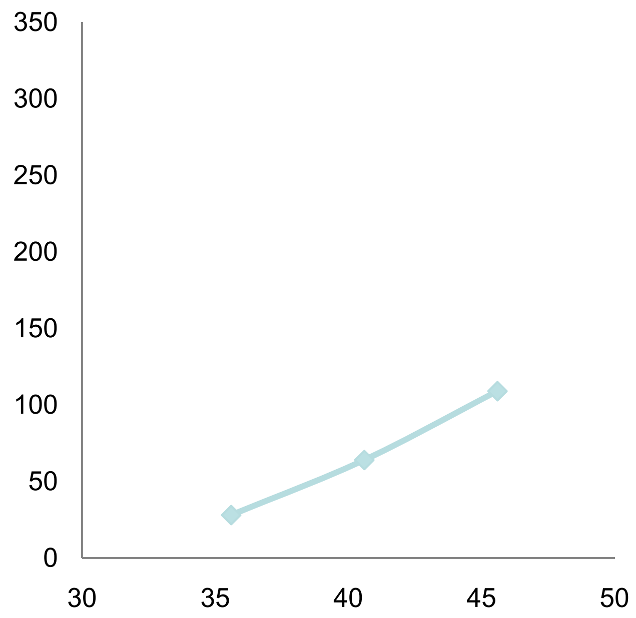
- Scenario & Shock:

  Reducing rate ↑ (=Quota ↓) => MAC ↑

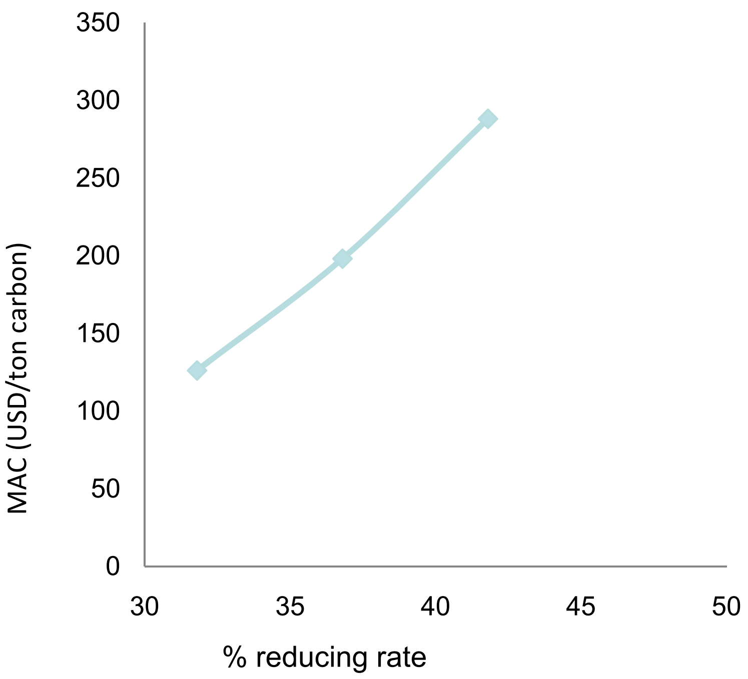
go2q	Emission reduction rate		
	baseline	5% reduction	10% reduction
usa	35.6	40.6	45.6
eu	22.4	27.4	32.4
jpn	31.8	36.8	41.8
roa1	35.7	40.7	45.7

MAC vs Reducing rate

USA



JPN



MAC line is positive shape:

- If emission reduction rate is increased, MAC is increasing

- Line shape

  The JPN's MAC line is steeper than USA's line

  It means that Japan's abatement cost is higher than USA

-> The Reason may be

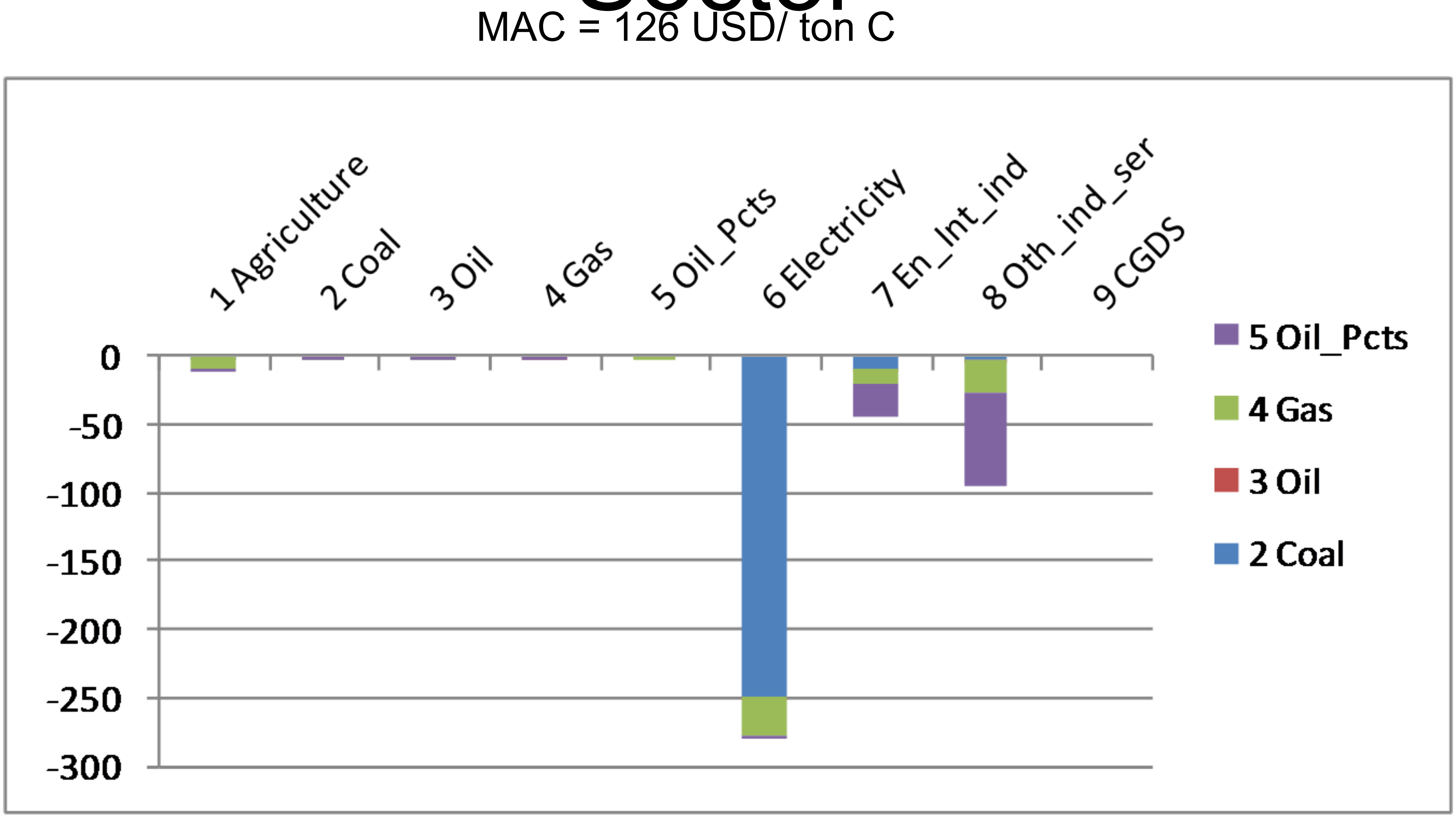
1) Q'ty of Emission per GDP unit of JPN smaller than USA

2) Production structure(or technology of energy usage) is different

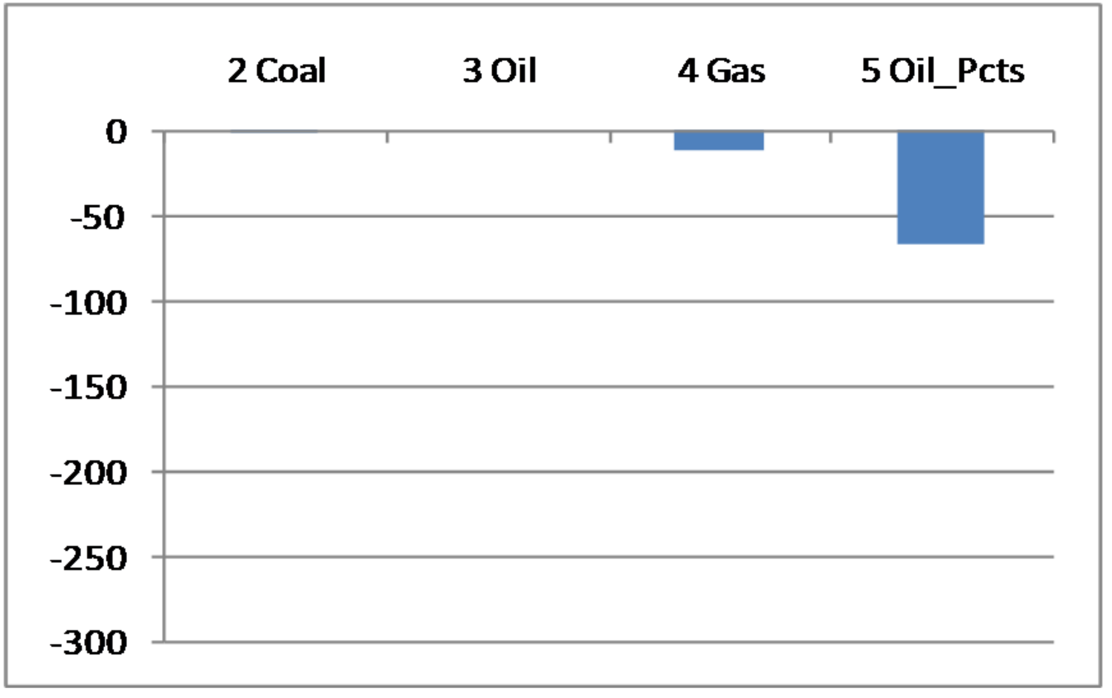
Understanding the Price of Carbon

- We know that it has to do with the structure of the economy
  - If it is easier to substitute away from energy intensive goods, then the cost of abatement is lower
  - An emergent property of many equations
    - Shadow price of carbon constraint

USA – Carbon Reductions by Sector

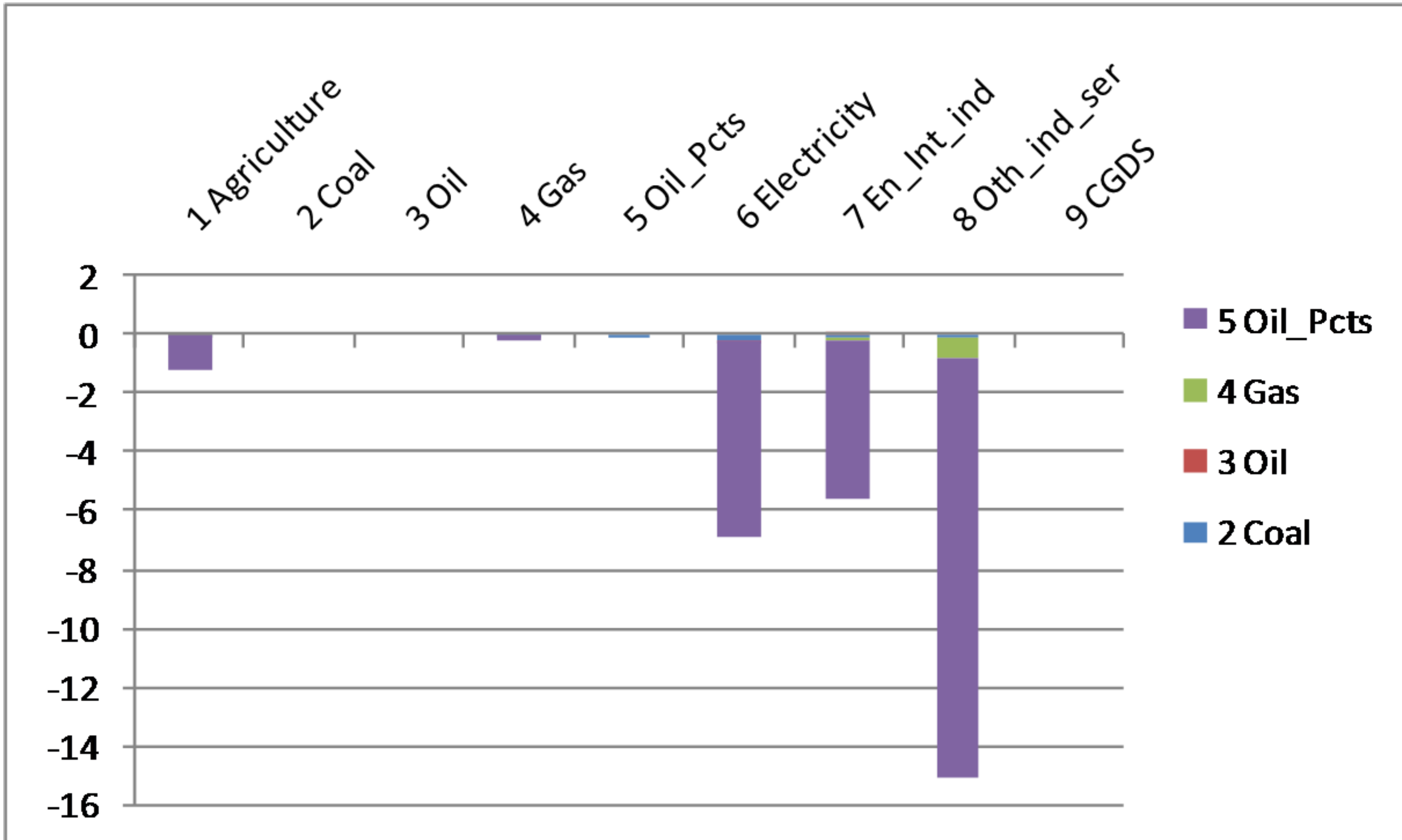


USA – Carbon Reductions by Private Consumption

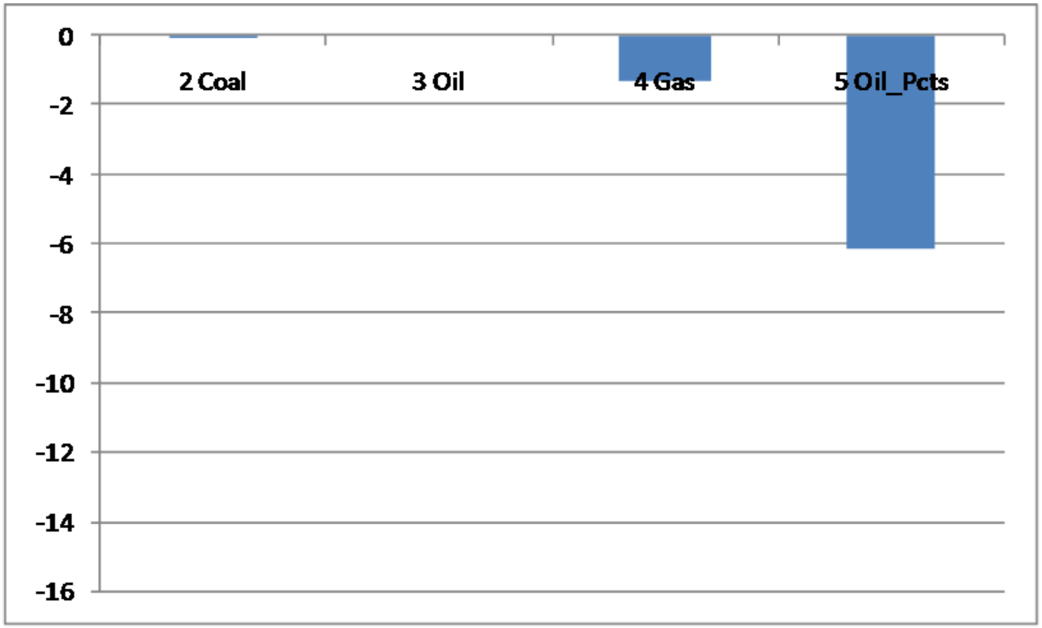


Japan – Carbon Reduction by Sector

MAC = 222 USD/ ton C



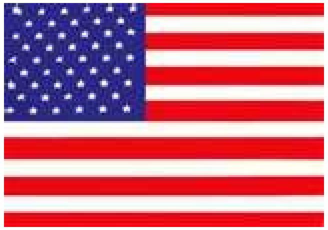
Japan – Carbon Reduction by Private Consumption

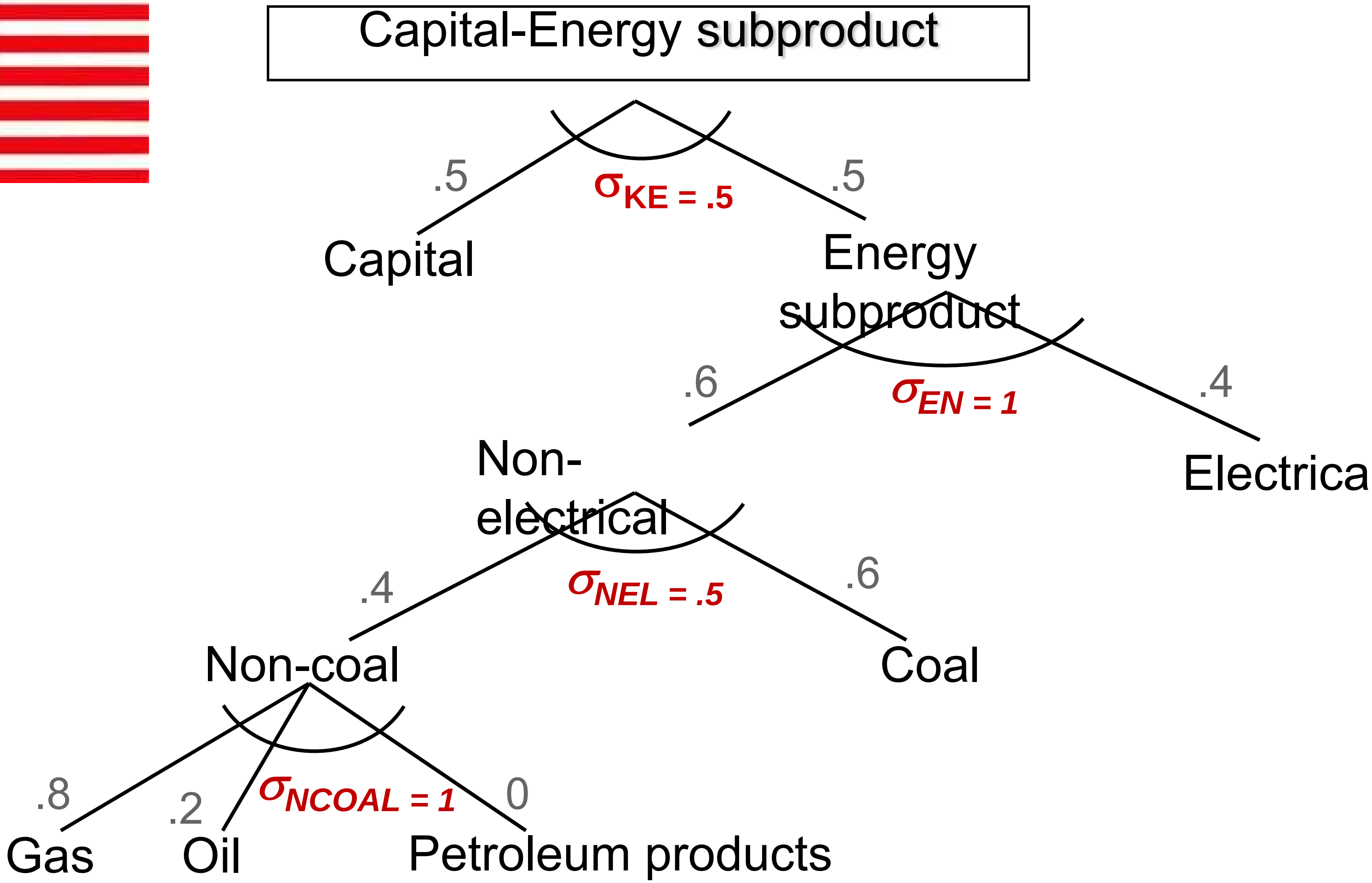


What is different about these economies?

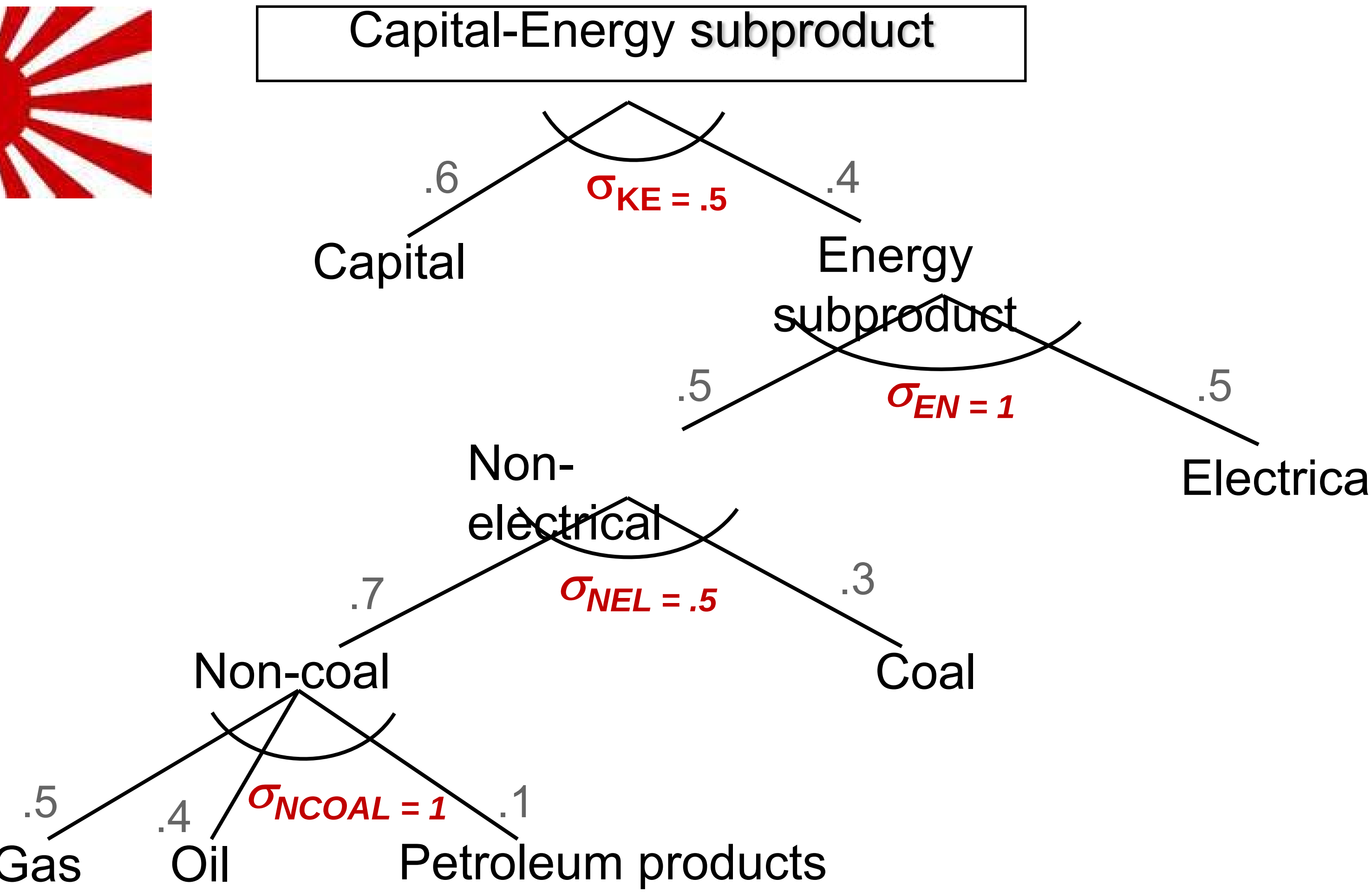
- Elasticity of substitution between energy intensive goods and others is determined by cost shares and CES parameters
- CES parameters are constant across regions and experiments…
- … Therefore, the cost shares determine the actual cost of substitution

USA Electricity Sector



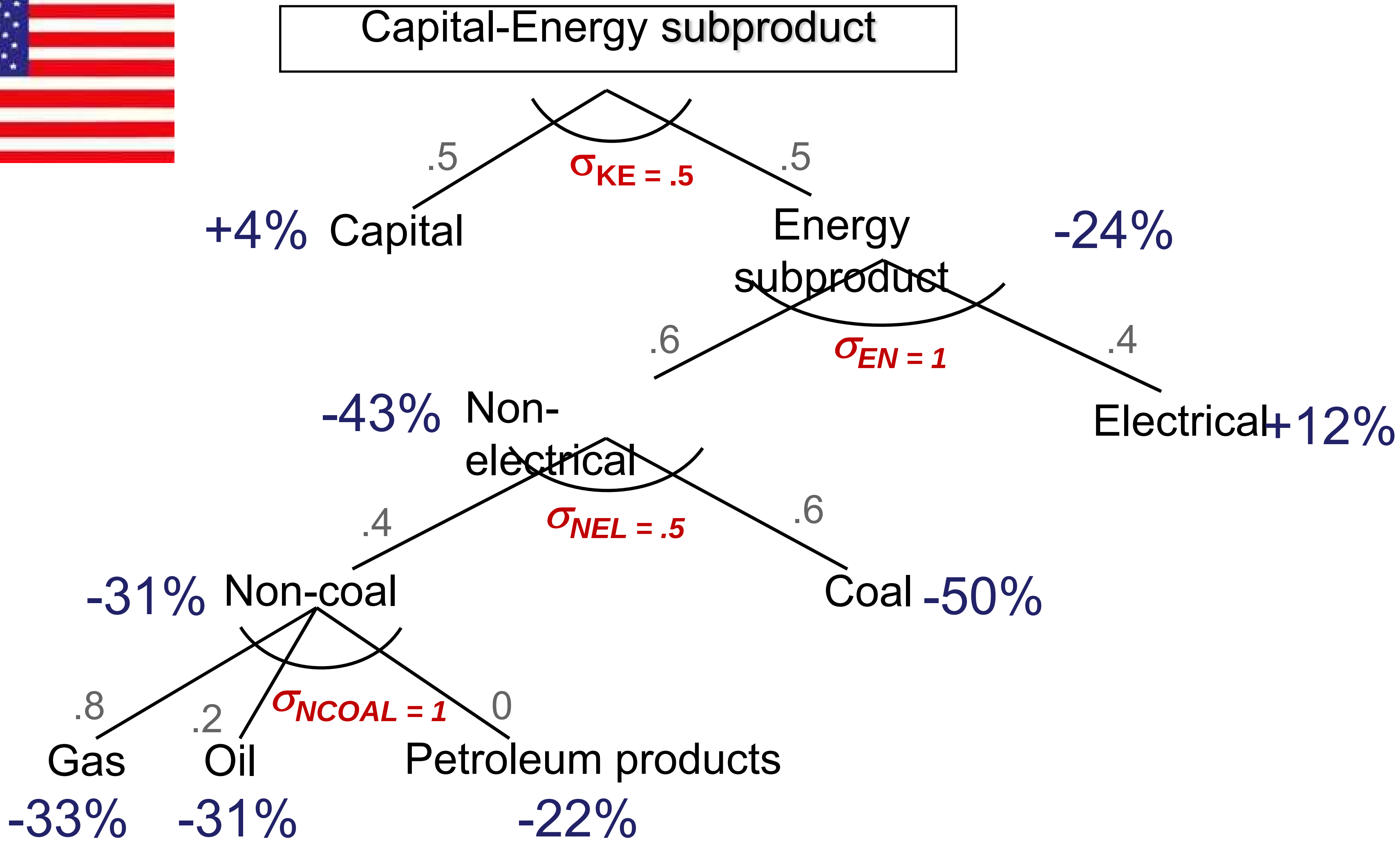


Japan Electricity Sector



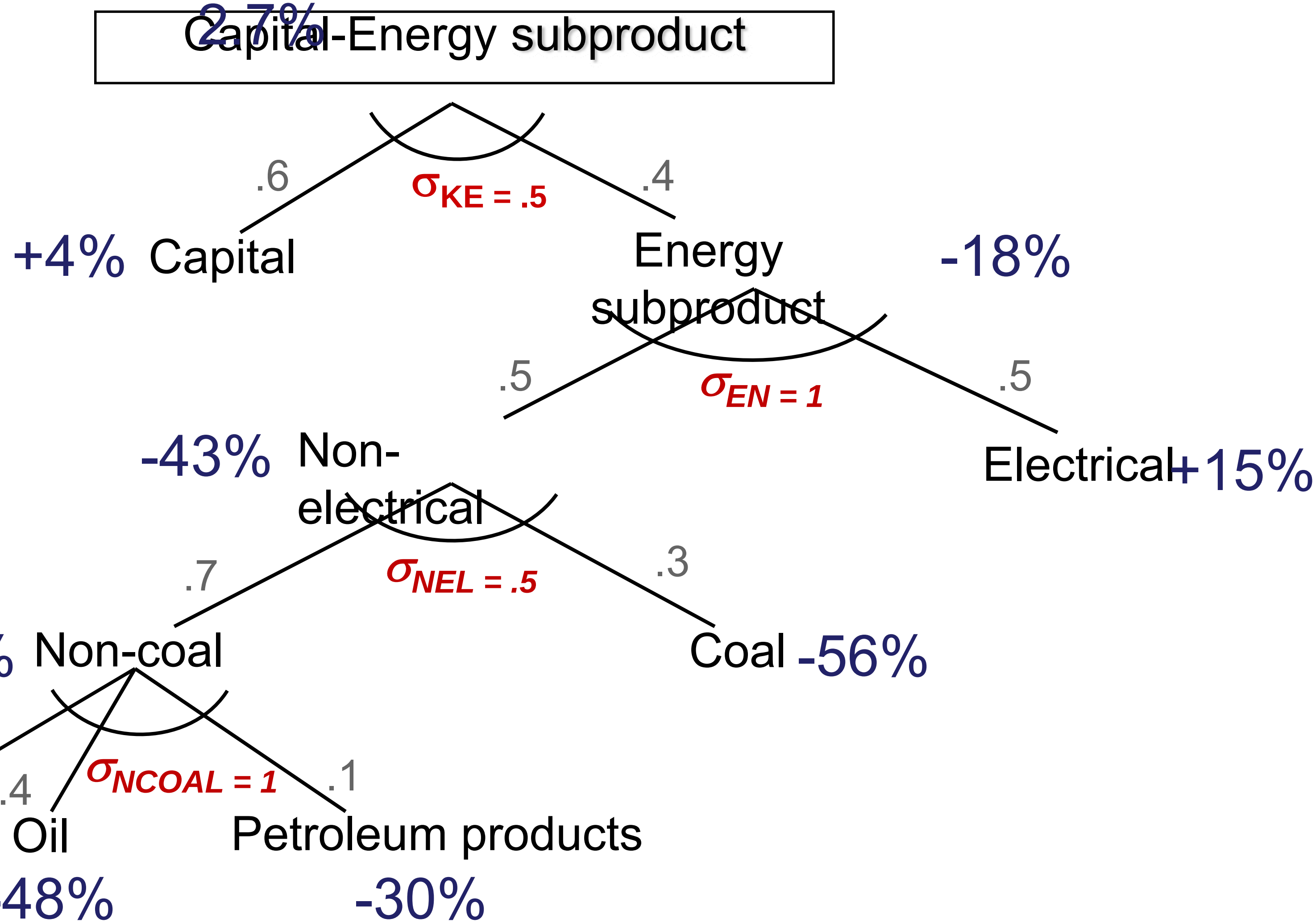
USA Electricity Sector

Whole Sector = -7%

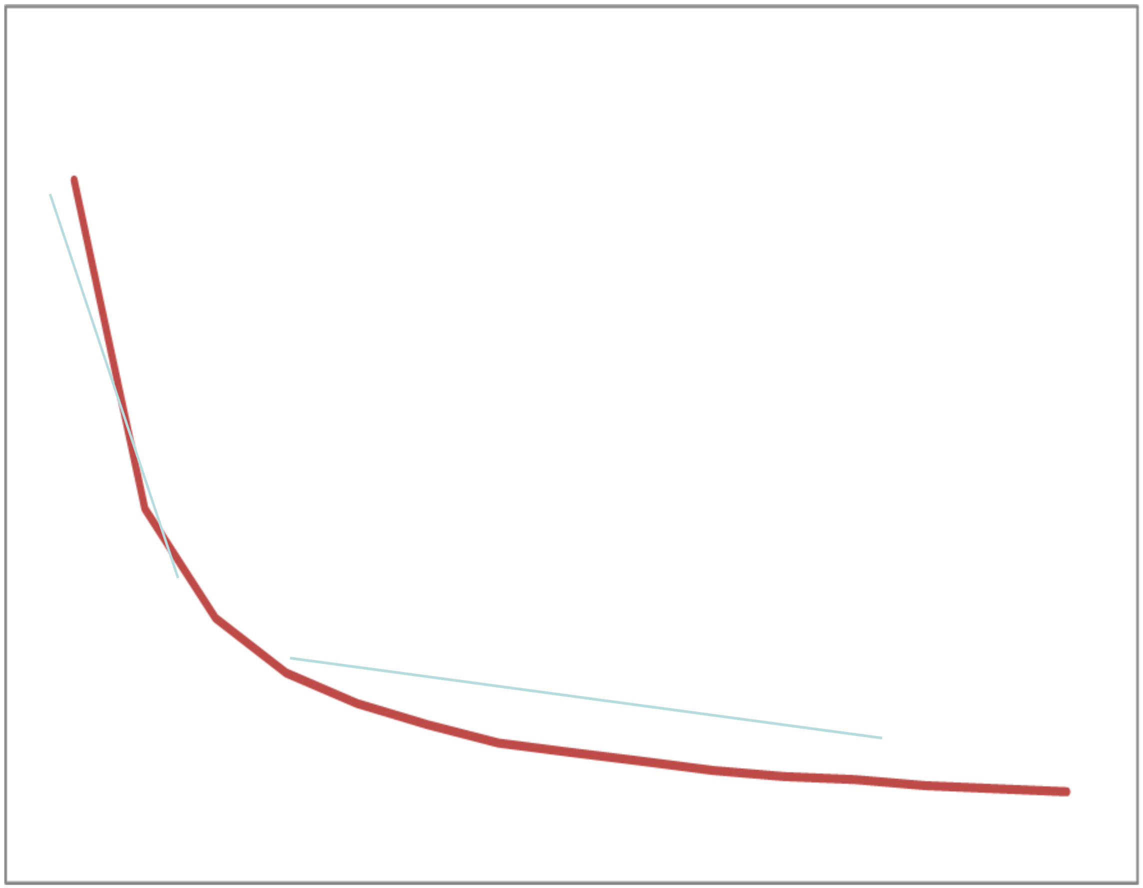


Japan Electricity Sector

Whole Sector = -2.7%



Lower Cost Shares Require Greater Price Signal to Change Quantity

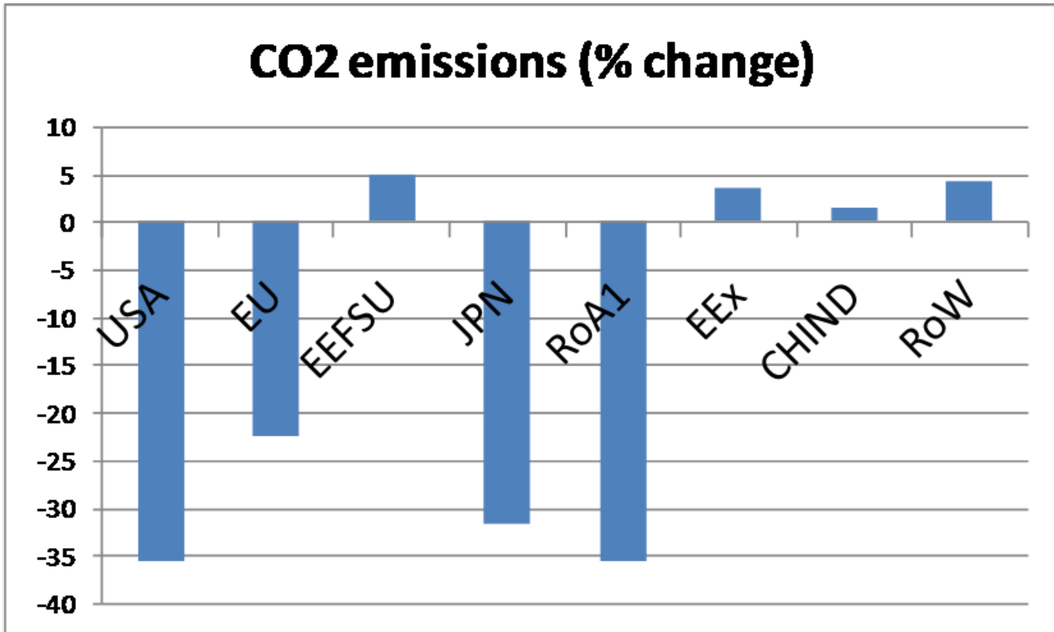


GHG Leakage

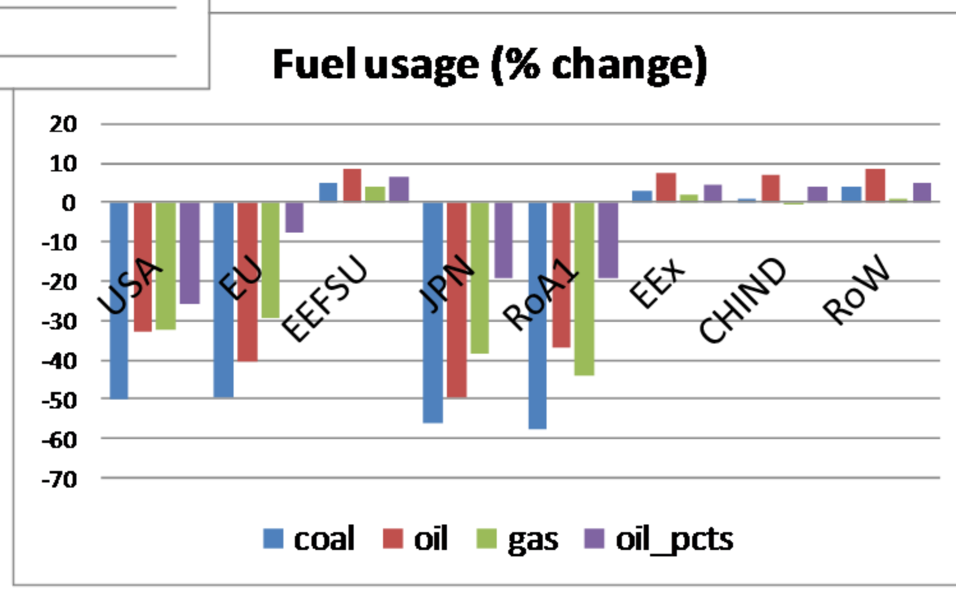
Leakage: What is it and where does it come from?

- Regions without planned reductions see an increase in emissions
  - Planned reductions (US, EU, JPN, RoA1)
  - Increases in emissions seen in non-capped regions (EEFSU, EEx, ChInd, ROW)
- Potential causes of emission leakage?
  - Participating regions import more energy intensive goods from non-participating regions (substitution)
  - Demand for carbon-intensive inputs goes down in participating regions (↓P) so demand increases in non-participating regions (expansion)

What do we see?

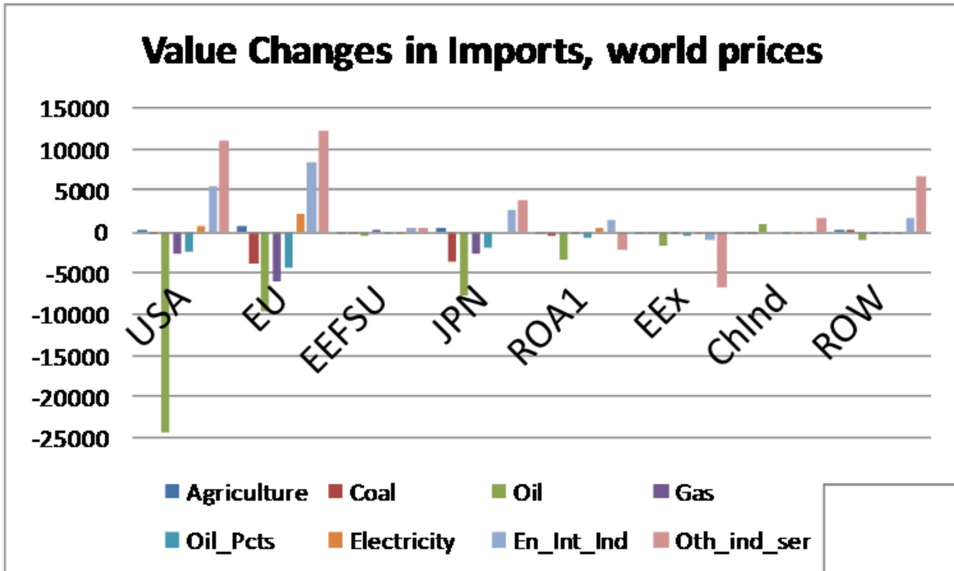


Emissions reductions targets:
US – 36%
JPN – 32%
EU – 22%
RoA1 – 36%



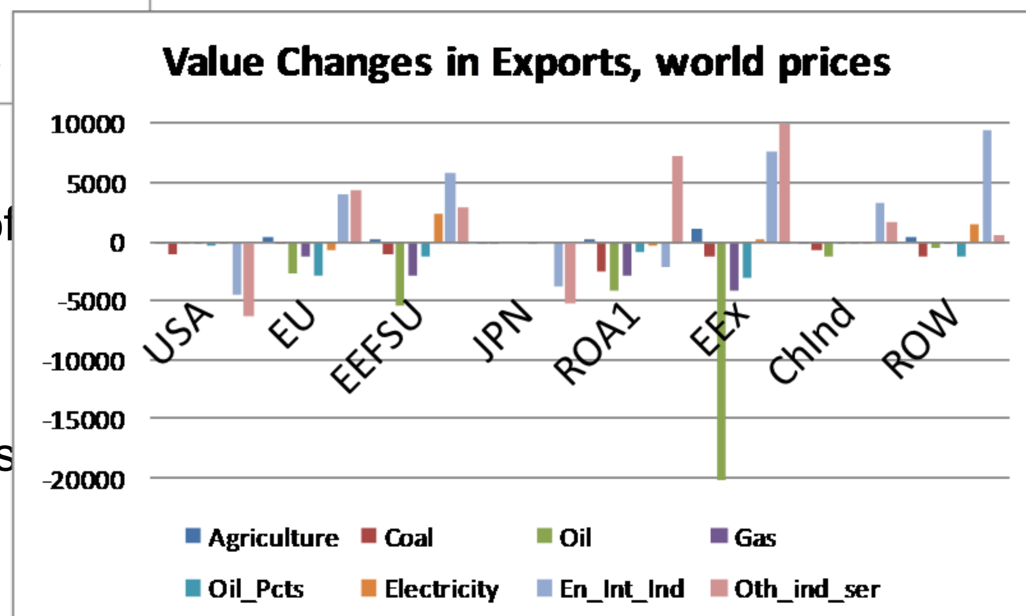
Corresponding decrease in fuel usage.

Where do these leakages come from?



Decrease in imports of coal, oil, and gas in participating regions.

Large increase in imports of carbon-intensive sectors in participating regions.



Corresponding increases in exports of carbon-intensive sectors in non-participating regions.

Additional increase in value of exports in EU!

What about the EU?

- Increase in value of exports for both En_Int_Ind and Oth_Ind_Ser
  - Relative prices increase, but not by as much as other regions

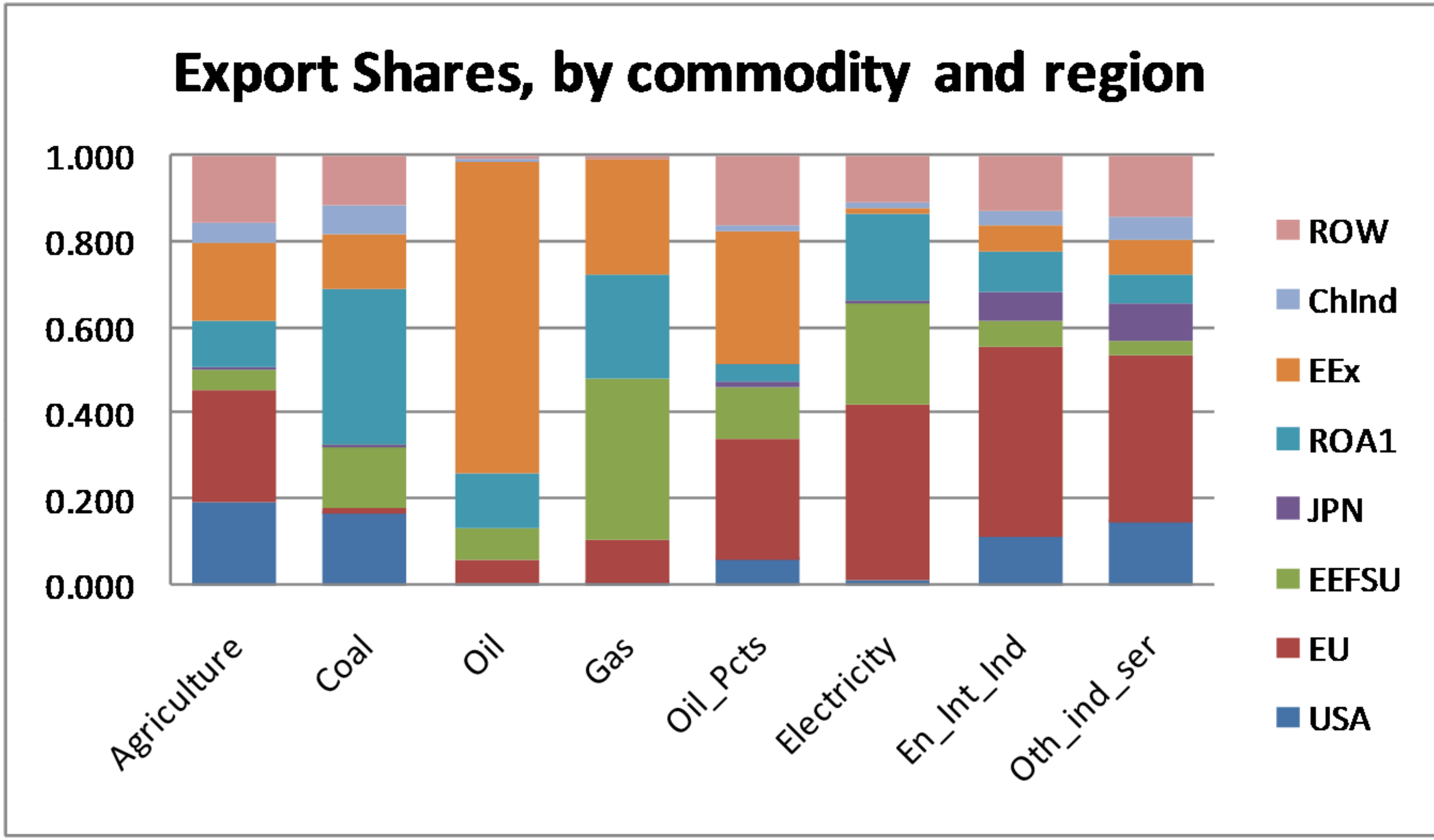
aggregate exports price index of I from region r [% change]								
	USA	EU	EEFSU	JPN	RoA1	EEx	CHIND	RoW
En_Int_ind	4.3	3.0	0.4	4.5	4.0	-0.2	0.8	1.0
Oth_ind_ser	1.2	1.0	0.5	1.3	0.5	-0.2	0.9	1.0

  - Reduction in quantity of exports

export sales of commodity I from EU to region s [% change]								
	USA	EU	EEFSU	JPN	RoA1	EEx	ChInd	RoW
En_Int_ind	0.02	-1.62	-4.85	-0.95	-0.15	-5.04	-4.82	-3.38
Oth_ind_ser	-0.64	-0.52	-1.09	-0.1	-1.49	-2.29	0.06	-0.09

  - Overall increase in value of exports

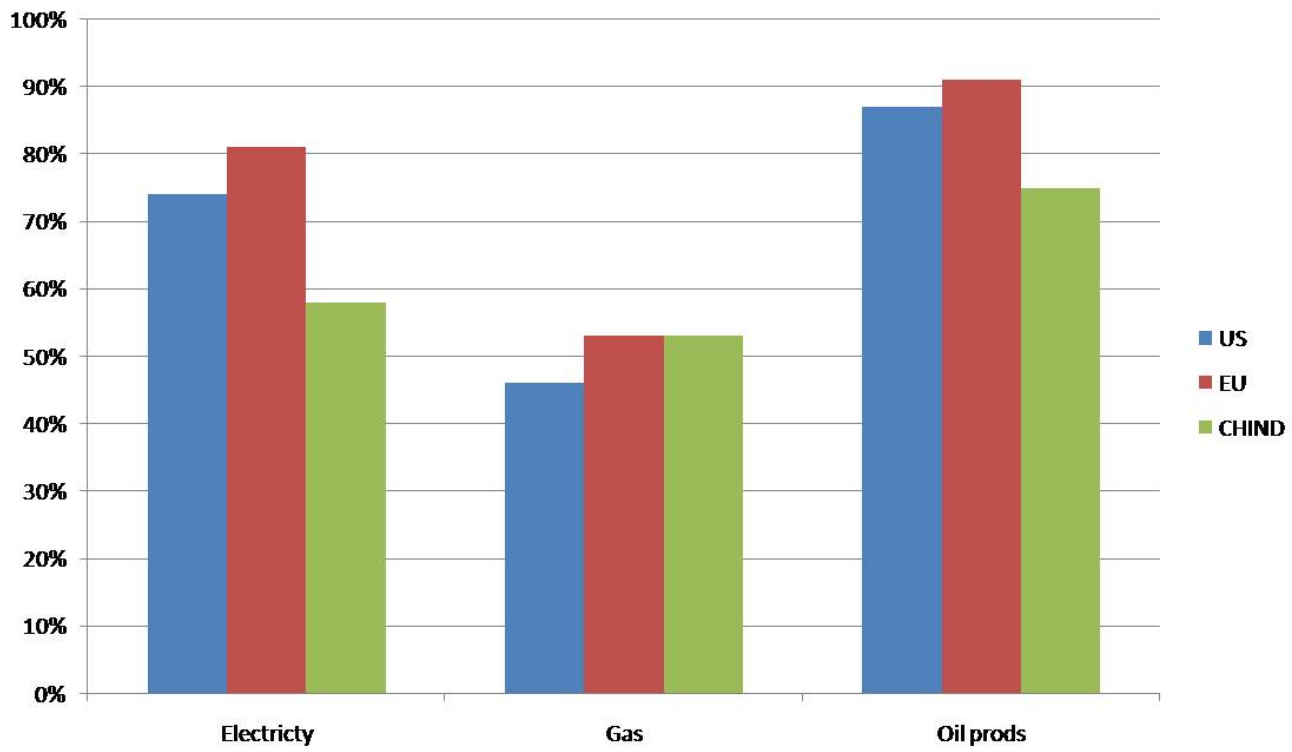
Export Shares



End use for consumption of fuels

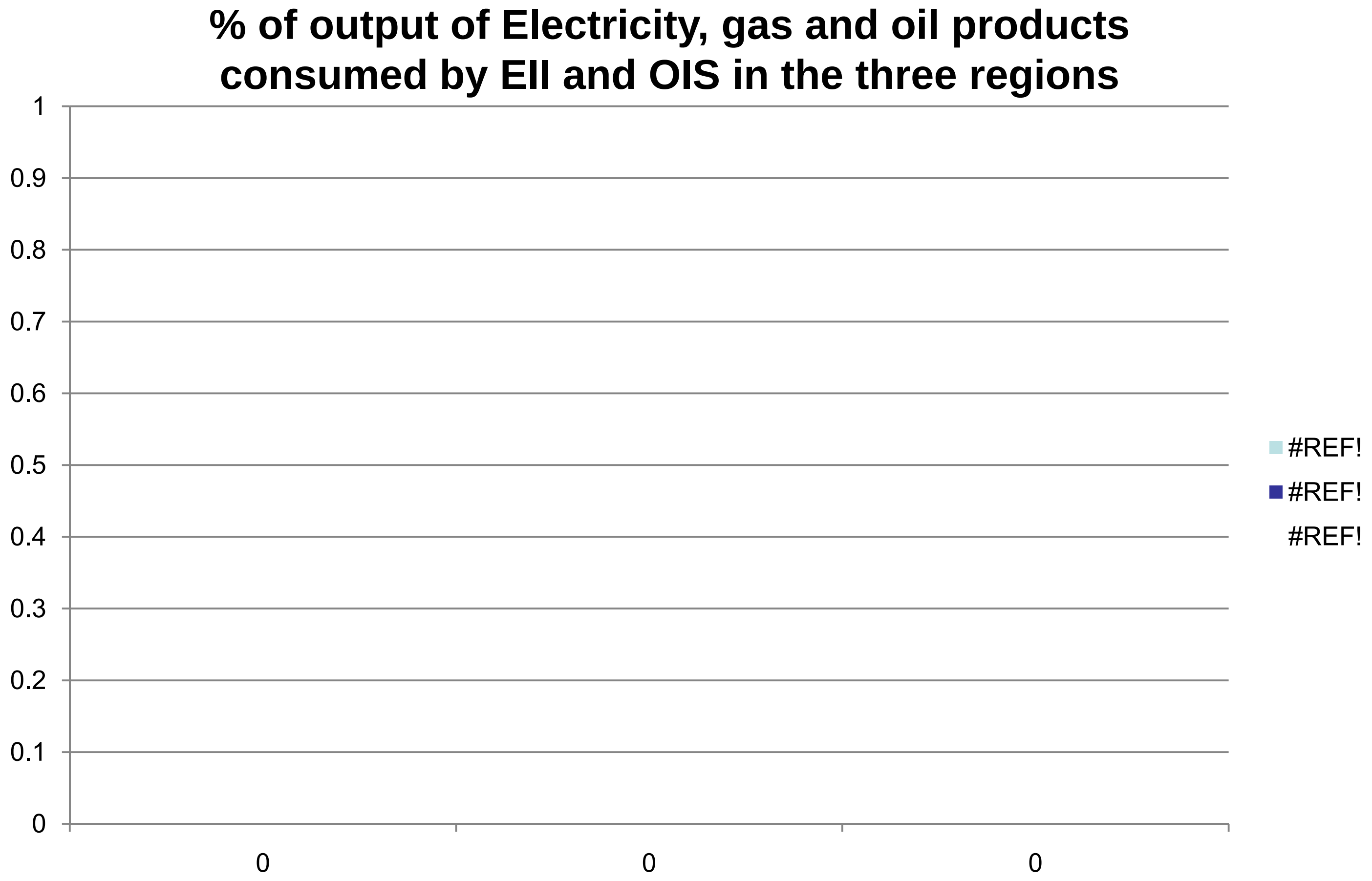
EII and OIS sectors are the major end uses for fuels

% of output of Electricity, gas and oil products consumed by EII and OIS in the three regions



End use for consumption of fuels

EII and OIS sectors are the major end uses for fuels



Impact on fuel markets

• Oil is a global commodity but coal and gas are continental (due to transport costs)

• Therefore there is a single global price for oil but not for coal and gas

• The carbon mandates increase the consumer price for fuels (which use it as an intermediate good) and decrease the producer price for fuels in annex 1 regions. This also raises the output price of energy consuming outputs

• World demand for all fuels falls but demand for fuels increases in the annex 1 regions

Two possible mechanisms of leakage

1. Sourcing of energy intensive goods from non-annex 1 countries i.e, increase in imports of EII and OIS from non-annex 1 regions

2. Intensification in the direction of use of carbon intensive fuels in non-annex I countries i.e., more use of coal and oil relative to natural gas

1. Leakage due to trade effects

Hypothesis : Share of imports from non Annex 1 increases due to the mandate

Evidence:
Domestic price of EII and OIS increased (pm) more relative to import price of EII and OIS in Annex 1 (pim)

As a result either domestic supply (qo) of EII and OIS declines in Annex 1 and imports of EII and OIS increased from non-Annex (qxs) or domestic supply decreased and imports decreased at a smaller rate

2. Leakage due to intensification in non-Annex 1

Hypothesis: Marginal production in non-Annex1 is more intensive in coal and oil relative to gas

Evidence:
In CHIND region
• EII output (qo) increased 1.54% while input demand (qf) for oil increased 5.27%, coal increased 2.71%, gas increased 0.42%

• OIS output (qo) increased 0.14% while input demand (qf) for oil increased 3.89%, coal increased 1.57%, gas decreased -0.89%

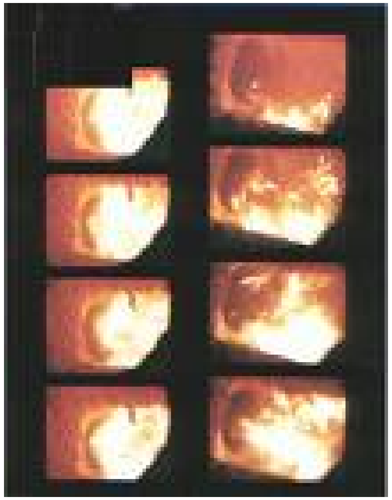
Carbon Emissions Technology Improvements: Coal

With contributions by Robert McDougall, Dileep Birur, and Terry Walmsley

Coal combustion

Coal

Combustion



Emissions intensity (EI) technology effect

Coal

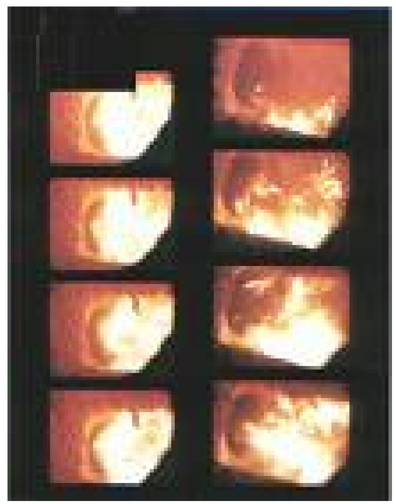
EI technology

Clean Coal "Sugar"

“Clean COAL” combustion with EI

Clean Coal “Sugar”

Combustion



EI assumptions

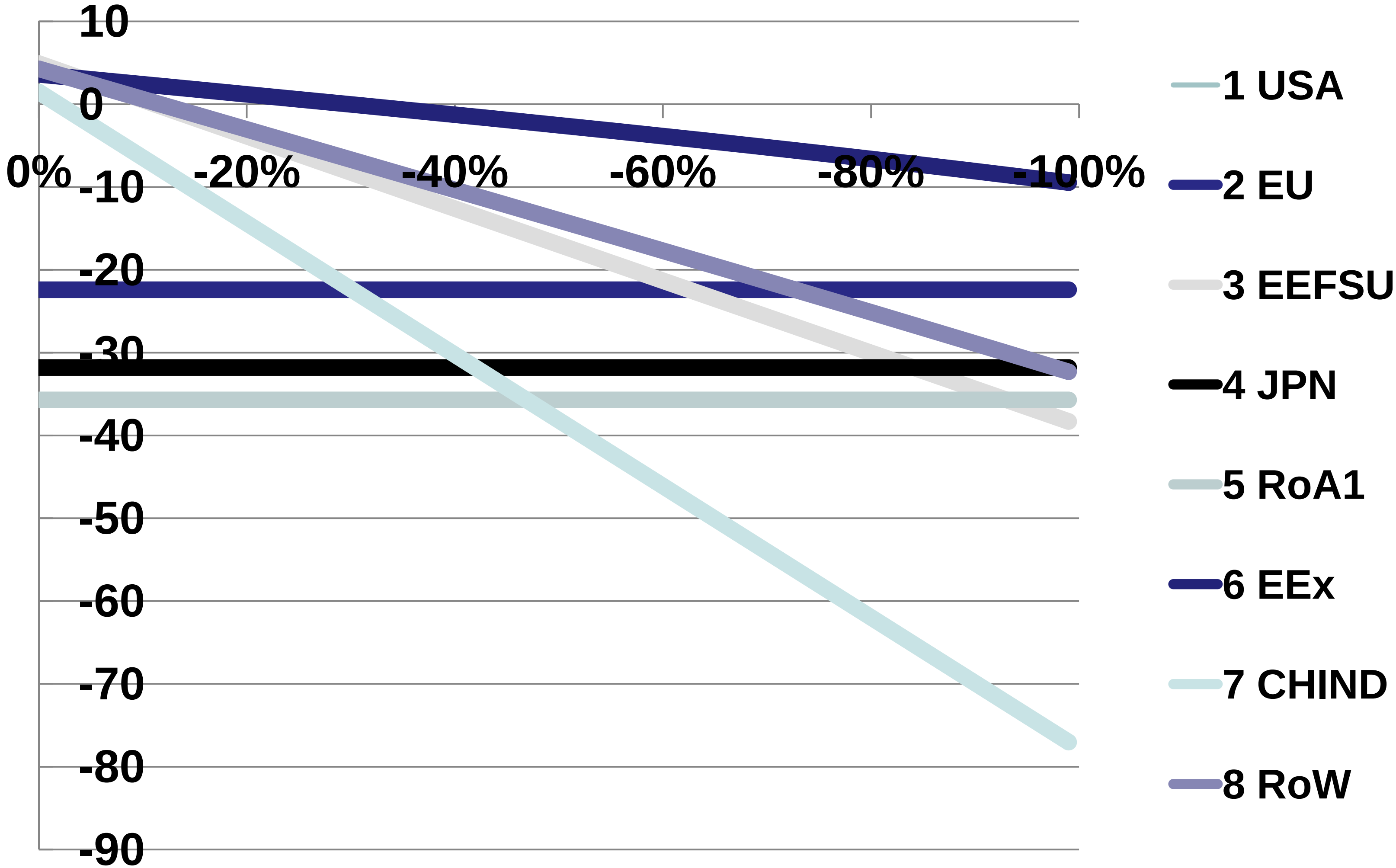
- Assume EI is cost free
- Therefore we get free “sugar” (coal)
- Utilized by all regions

Extension to GTAP-E emission eccounting

- GTAP-E accounts for emissions
  - Main model equation… gco2pd(i,r) = qpd(i,r);
- Extend the emissions accounts to also capture Emission Intensity (EI)
  - EI represents emissions reduction technology
  - Levels equation… GCO2PD = QPD*EI
  - Updated main model equation becomes… gco2pd(i,r) = qpd(i,r) + ei(i,r);

Shock the model ⇨ Results

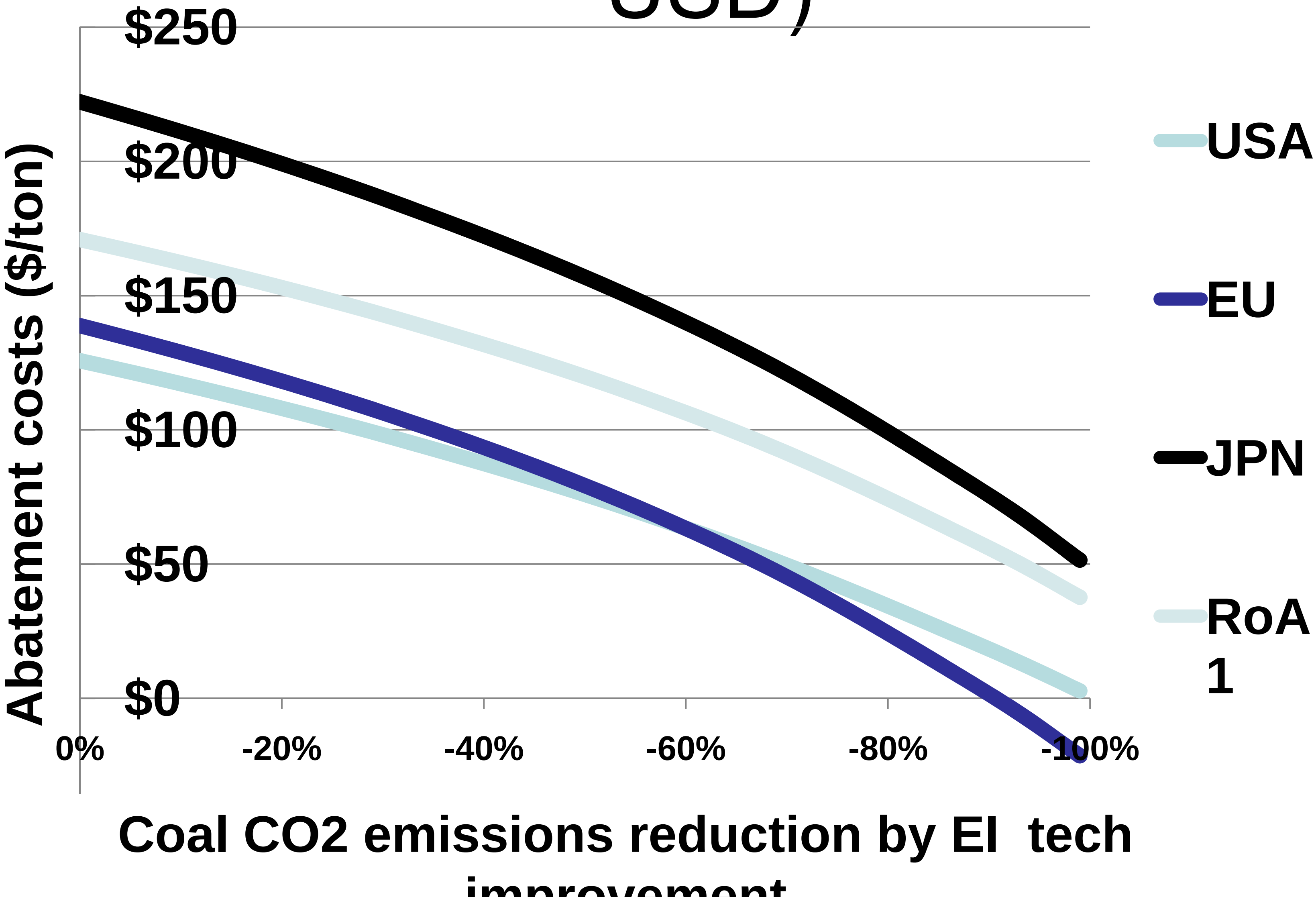
Percent reduction in emissions



Welfare effect with EI

	0%	-5%	-30%	-90%	-99%
USA	-0.24	-0.23	-0.17	-0.02	0
EU	-0.39	-0.37	-0.27	0.06	0.12
EEFSU	-0.4	-0.4	-0.35	-0.07	0.02
JPN	-0.53	-0.51	-0.44	-0.2	-0.15
RoA1	-1.19	-1.17	-1	-0.36	-0.21
EEx	-1	-0.98	-0.85	-0.23	-0.06
CHIND	0.08	0.08	0.06	0.01	0
RoW	0.16	0.16	0.14	0.04	0.01

Abatement costs (carbon tax) per ton of carbon emissions (1997 USD)



Leakages before and after EI tech

	% reduction in Emissions no EI	% reduction in Emissions EI = -90%
Leakage rate (incl. EEFSU)	**11%**	**-134%**
Leakage rate (excl. EEFSU)	**7%**	**-82%**

Conclusions

- Introduction of EI tech:
  - achieves Kyoto targets without emissions trading
  - Non-Annex I countries reduce emissions
  - Improvement in welfare in EU, EEFSU and RoW
  - Leakages are eliminated