Flexible regulation for climate policy

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(Research with Dallas Burtraw and Karen Palmer from Resources for the Future)

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Motivation: High emissions from coal

Currently

- 40% of US CO_2 emissions are from the electricity sector
- 60% from fossil fuels – 44% from coal

- EIA forecasts:
- new 27 GW of conventional coal by 2035
- 9% increase in CO2 emissions by 2035

Tough to reduce CO_2 emissions from electricity sector given this pattern of investment !!

Motivation: Uncertain Climate Policy

- Federal cap and trade:

  …was dead. Now it will be deader!
- Future of regional programs is uncertain
- Regulation of GHGs under Clean Air Act
  - Likely to involve standards for new and old plants
  - Initial standards are likely to be modest
  - Efficiency and co-firing will be included

No price on CO_2 (or low price) → little disincentive to invest in conventional coal

Want large reductions from Coal-fired generation ?

→ more stringent standards are necessary !!

Motivation

- If we agree that CCS is needed…

  What can Policy Makers do to accelerate CCS deployment before a Federal CO_2 Policy is implemented?

Policy Tool 1: CO_2 Emissions Standard

- This already exists for SO_2 and NO_x

- Also exists for CO2 → California's (S.B. 1368) :
  - 1,100lbs of CO_2/MWh (like a NGCC plant)
  - applies to all new-long term financial commitments
    - Power generated within the state
    - Power imported

- Has been included in previous proposals
  - American Power Act (Kerry/Lieberman)
  - Clean Air/Climate Change Act of 2007 (Alexander/Lieberman)
  - Clean Coal Act of 2006 (Kerry)

- U.S. public has a preference for standards over cap-and-trade

Policy Tool 1: CO_2 Emissions Standard

- Is CCS ready?
  - Costs are high
  - Performance and long term O&M is uncertain
  - Physical infrastructure is undeveloped
  - Regulatory infrastructure is undeveloped

- Possible Investors response?
  - Hold off on investing in new coal facilities until costs come down and experience grows

Issues with Standards

- Standards for new plants can discourage new investment
  - Economics literature (Gruenspecht 1982, Maloney and Brady 1988, Nelson et al. 1993, Stavins 2007) provides examples

- Delays in construction of new base load **coal** capacity could
  - **raise CO_2 emissions** relative to no policy baseline
  - limit opportunities for **learning** by doing and delay movement toward lower costs for CCS
  - **limit supply** of new generation capacity, which could lead to higher electricity prices
  - Increase reliance on **natural gas**, resulting in higher gas prices

The best of two worlds

Advantage of having a Standard today:

No plant built today can get away with high CO_2 emissions

Disadvantage of having a Standard when CCS is not ready:

•Delay investment in coal-plants
•Delay learning in CCS
•Keep dirtier plants longer

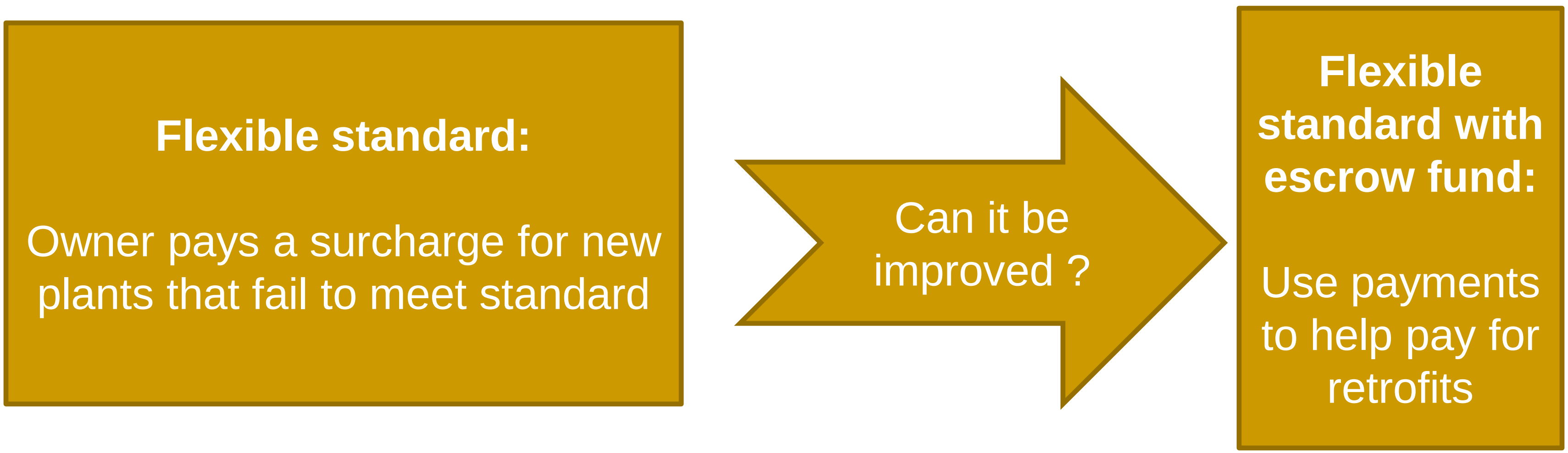
Keep advantages and eliminate disadvantages ???

Flexible standard

Policy Tool 2: **Flexible** CO_2 Emissions Standard

- Owner of facility pays an emissions surcharge for new plants that fail to meet the maximum CO_2 emission rate standard
  - (additional to any CAT requirement) (Roberts and Spence 1976)
- When plant is retrofitted surcharge payment stops
- Alberta has such a policy for industrial sources ($15 surcharge)
- Would require legislative authorization under US CAA

Improving the flexible standard



Policy Tool 3: **<u>Flexible</u>** CO_2 Emissions Standard with **escrow fund**

- Same as Policy 2:

  Owner of facility pays an emissions surcharge for new plants that fail to meet the maximum CO_2 emission rate standard

- But it includes the creation of an **escrow fund:**

  financed by the surcharge that **investors can draw on to help finance the retrofitting of their facilities with CCS**

Research objective

- Is there a flexible performance standard that keeps the benefits of the strict version without its failures?
  - What is the minimum surcharge value for which flexible standard is better than inflexible?
  - How should the escrow fund be implemented?
    - How much can be recovered by the surcharge payer?
    - Expiration? Interest?
  - How is the technology choice affected by Tools 2 and 3?

Hypothesis:

Tool 1: An inflexible emissions standard:

- delays construction of new generation facilities.
- increases emissions.

Tool 2: A flexible standard:

- Would cause investment in **new generation** technology to occur sooner.
- Should lead to a reduction in emissions.
- Profits would not fall.
- An increase in the surcharge (B) should accelerate **CCS investment**.
- An appropriate emission surcharge (B*) leads to investment in CCS by the same point in time as would a traditional emission performance standard.
  - B>B* yields CCS (weakly) sooner than an inflexible standard.

Tool 3: Escrow fund:

- Construction of new generation capacity should occur no later.
- CCS installation should occur no later.
- Emissions should not rise.
- Profits for an investor would not fall.

Approach

I. Analytic framework

II. Simulation – Optimization framework

For all policies

1. Simulate investors decision over 40+ years
2. Find emissions over 40+ years
3. Find NPV over 40+ years
4. Compare policies (under uncertainty and ~certainty)

*Policies:

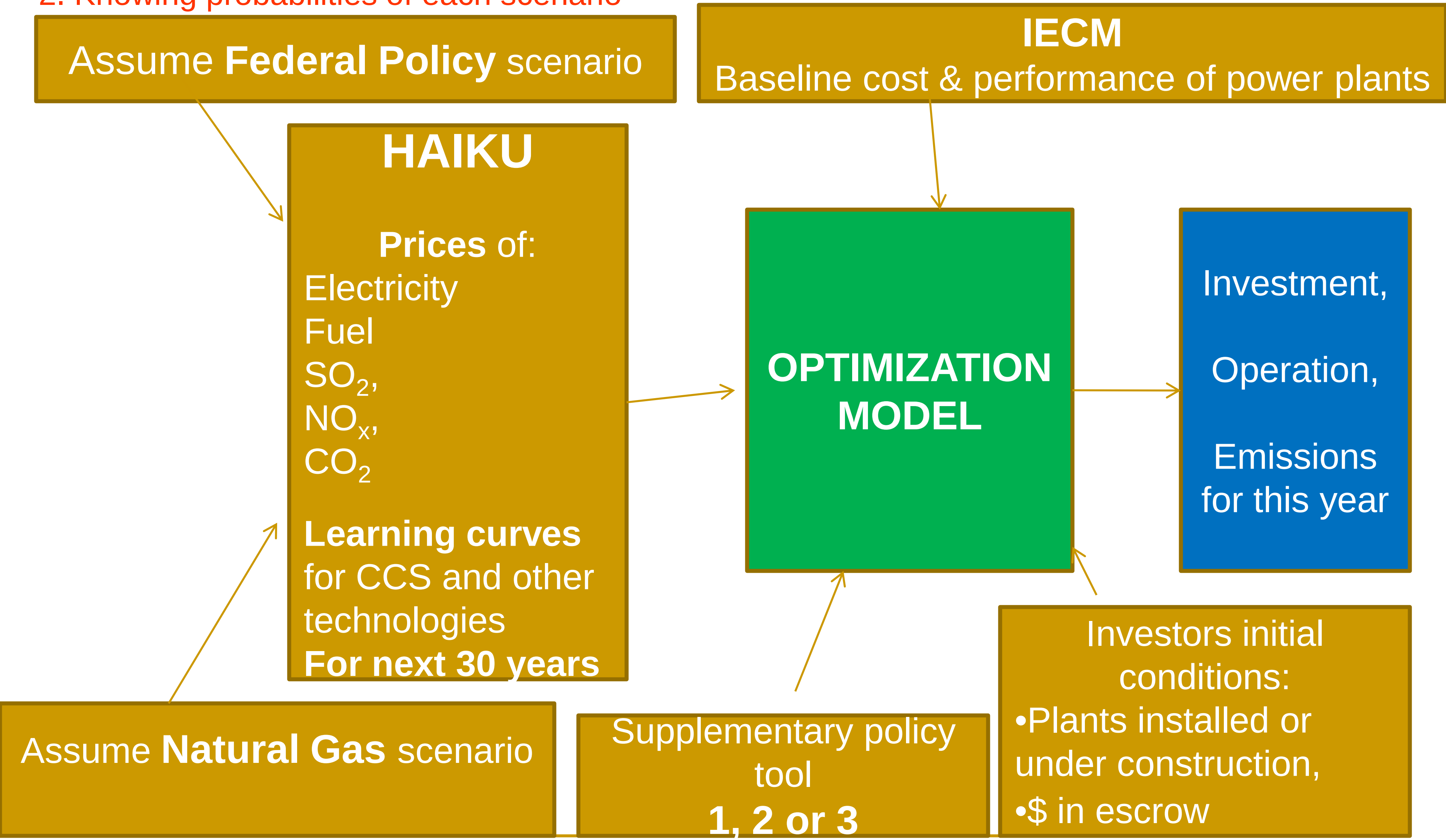
1. baseline,
2. Inflexible standard
3. Flex with surcharges $1/ton – $14/ton
4. Flex with escrow surcharge $1/ton - $14/ton

30 different policies in total

Every year solve an optimization problem

1.knowing the scenario for the next 30 years

2. Knowing probabilities of each scenario



Scenarios: Federal Policy & NG Prices

Scenario	CO_2 prices	NG Price
1	No federal climate policy. CO2 price = $0	Low
2	CO2 Prices are 50% of S.280	Low
3	CO2 prices of S.280	Low
4	CO2 Prices are 150% of S.280	Low

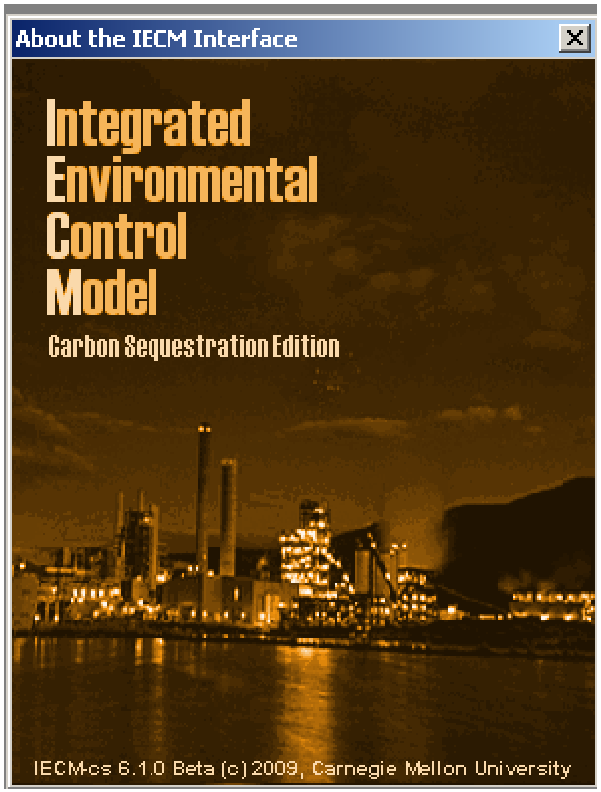
Haiku Electricity Market Model

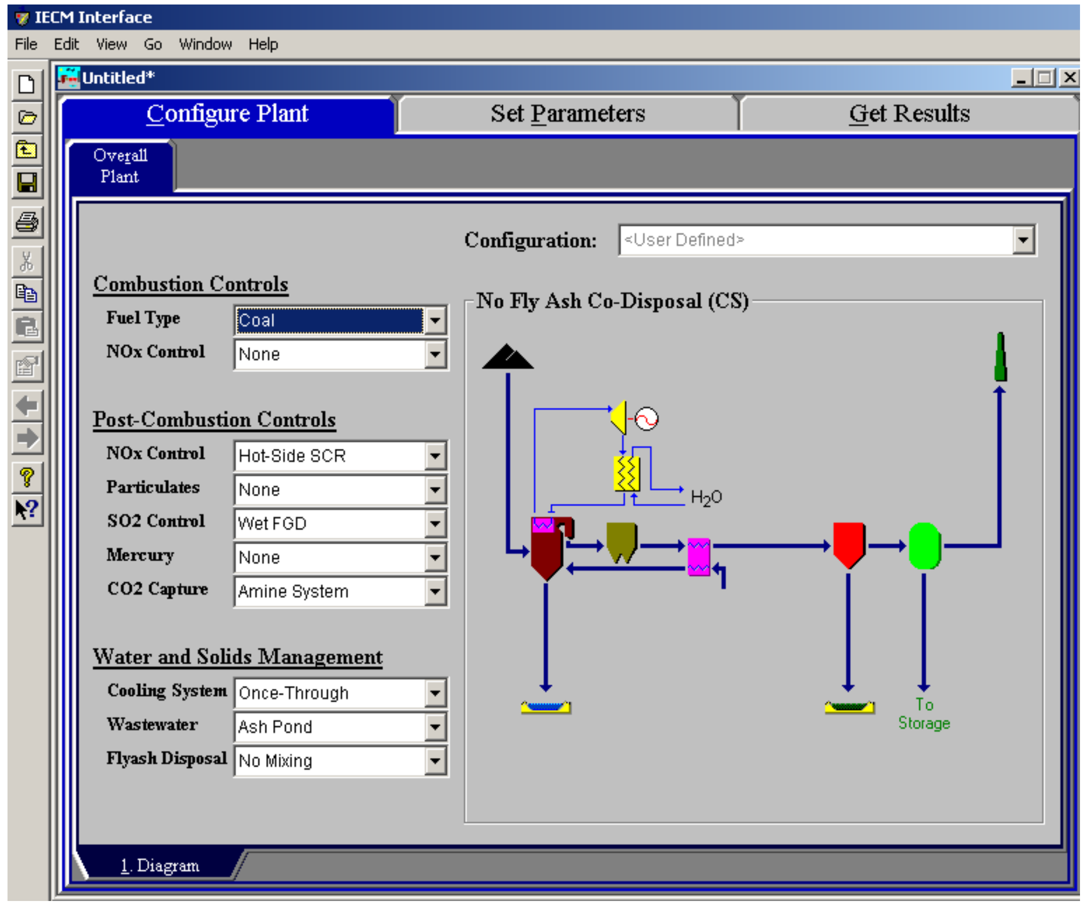
- Solves for equilibria in 20 regions of the US
- Output for an extended time horizon:
  - New capacity investment
  - Capacity retirement
  - System operation
- Consistent forecasts of relative prices of fuel, allowance prices, and wholesale electricity prices
- We look at results for the MAIN region (Illinois/Wisconsin)

Electricity price, emissions and CO_2 price for 2025 in 2004 $ (From Haiku model under mid NG price)

(2004 dollars)	***Baseline***	***50% S280***	***S280***	***150% S280***
National Average Electricity Price (2004$/MWh)	$82.19	$88.38	$95.66	$102.24
National Emissions (million tons)	3,166	2,625	2,068	1,491
Allowance Price ($/ton)	$0.00	$12.74	$26.09	$38.23

Integrated Environmental Control Model – Carbon Sequestration edition

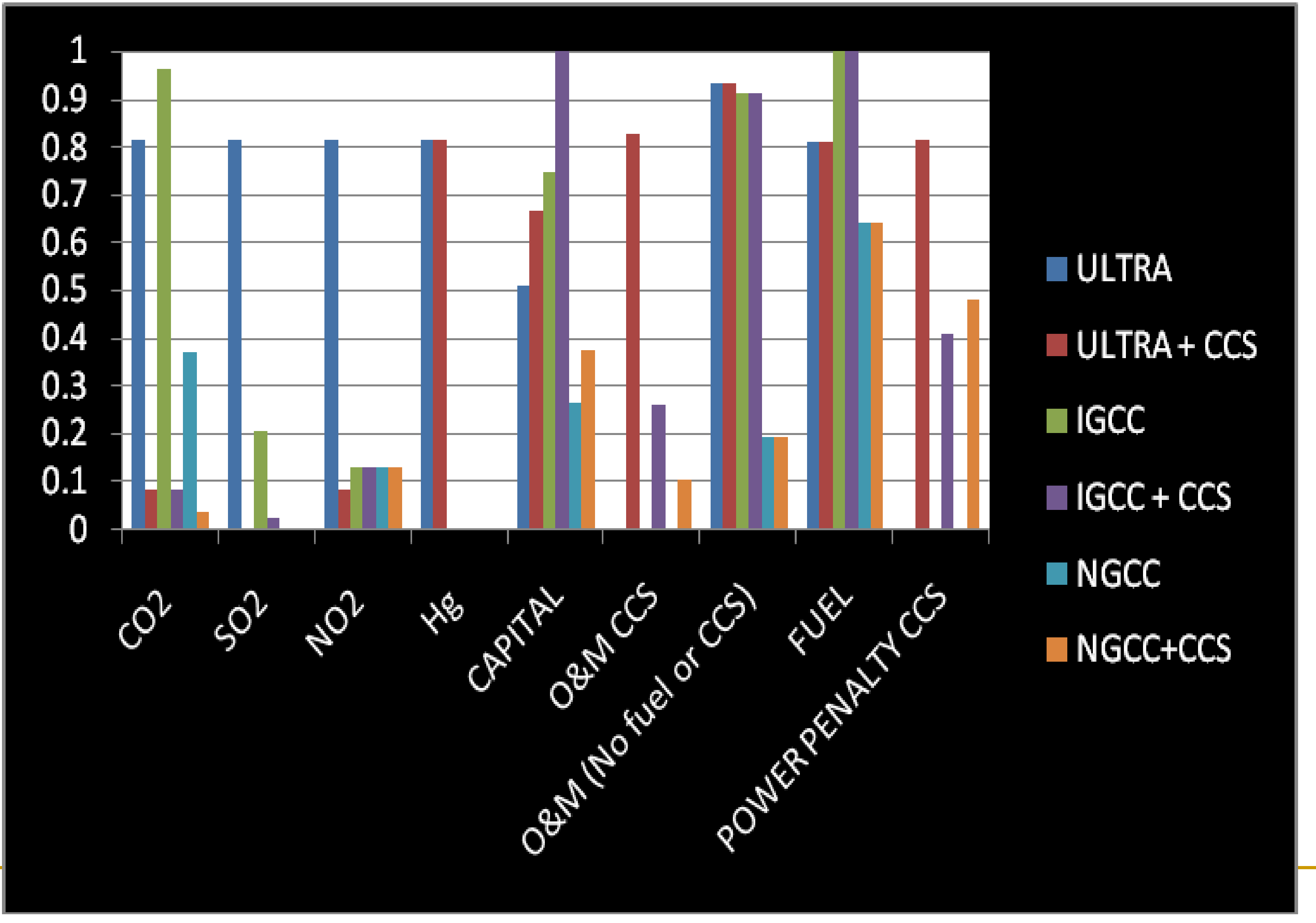




Possible investments

Configuration Installation	PreRequisite Configuration	Capital Cost ($M2004)(2)
1. Subcritical		1,480.00
2. Subcritical+CCS		2,049.00
3. CCS on Subcritical	1	682.80
4. Supercritical		1,541.00
5. Supercritical+CCS		2,048.00
6. CCS on Supercritical	4	608.40
7. Ultrasupercritical		1,529.00
8. Ultrasupercritical+CCS		2,003.00
9. CCS on Ultrasupercritical	7	568.80
10. IGCC		2,239.00
11. IGCC + CCS		3,003.00
12. CCS on IGCC	10	993.20
13. NGCC		794.50
14. NGCC+CCS		1,119.00
15. CCS on NGCC	13	389.40

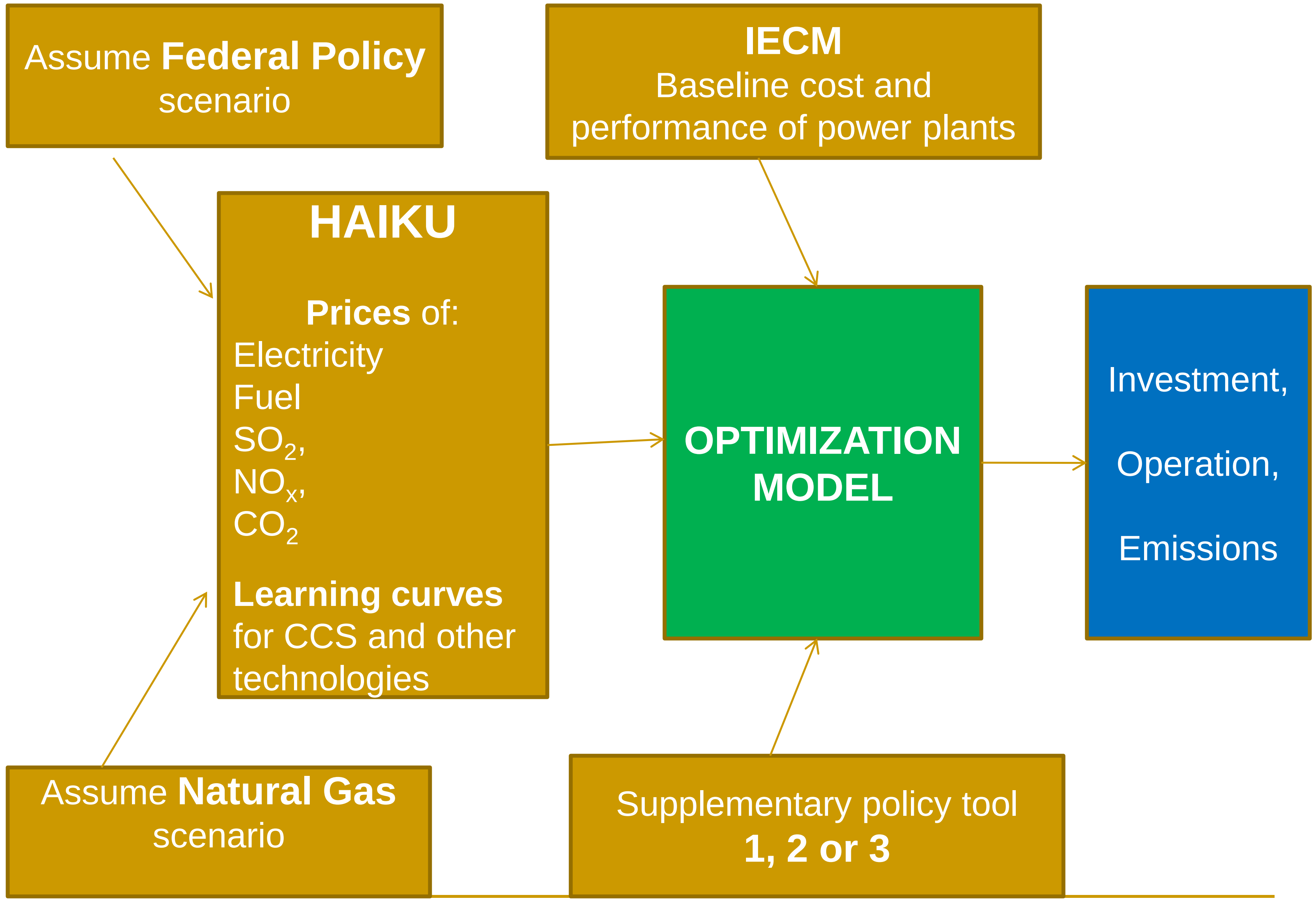
Relative emissions and costs



Additional assumptions under all scenarios

- Capital cost penalty on CCS
  - Capital costs are 2x today's costs in year 1 and decline linearly with time

- Costs of CCS retrofits are higher than new installations
  - 30% higher for CCS
  - 20% higher for sub, super, ultra and NGCC


Assume Federal Policy scenario
IECM
Baseline cost and performance of power plants
HAIKU
Prices of:
Electricity
Fuel
SO_2,
NO_x,
CO_2
Learning curves for CCS and other technologies
OPTIMIZATION MODEL
Investment,
Operation,
Emissions
Assume Natural Gas scenario
Supplementary policy tool
1, 2 or 3

Optimization model – almost **Perfect foresight**

- Investor has perfect foresight for 30 years
- Each year can see next 30 years
  - When making decision in year 1, is able to see info for years 1 to 30
  - When making decision in year 2, is able to see info for years 2 to 31 etc..
- And we are looking at 43 years of investment and associated costs and emissions

Optimization model - **Uncertainty**

- Multi-stage, Stochastic, Mixed integer programming (MIP) problem
  - First stage decision: Investment & operation in year 1
  - Multi-stage decision: Investment & operation in years 2,3,..30 under scenarios 1, 2, 3,…12

- Characterization of uncertainty
  - Parameters of each of 12 scenarios are known
  - Initially investor thinks every scenario is equally likely to occur
  - Probability of actual scenario increases every year and the probability of the other scenarios decreases
  - Uncertainty is resolved in 12 years

Optimization Model

- Objective Function: Minimize (–profits)

- Profits:
  - Revenue – Costs

- Revenue:
  - ElectricityPrices * ElectricityGeneration

- Costs:
  - CapitalCosts + O&M Costs

- Capital costs:
  - Minus escrow account recovery if Policy Tool # 3

- O&M Costs
  - Fuel, Emissions Allowances, Surcharge if policy tool 2 or 3

Optimization Model – Constraints for all policies

- A configuration needs to be available before it is used
  - Takes 2 years to install a power plant or retrofit with CCS

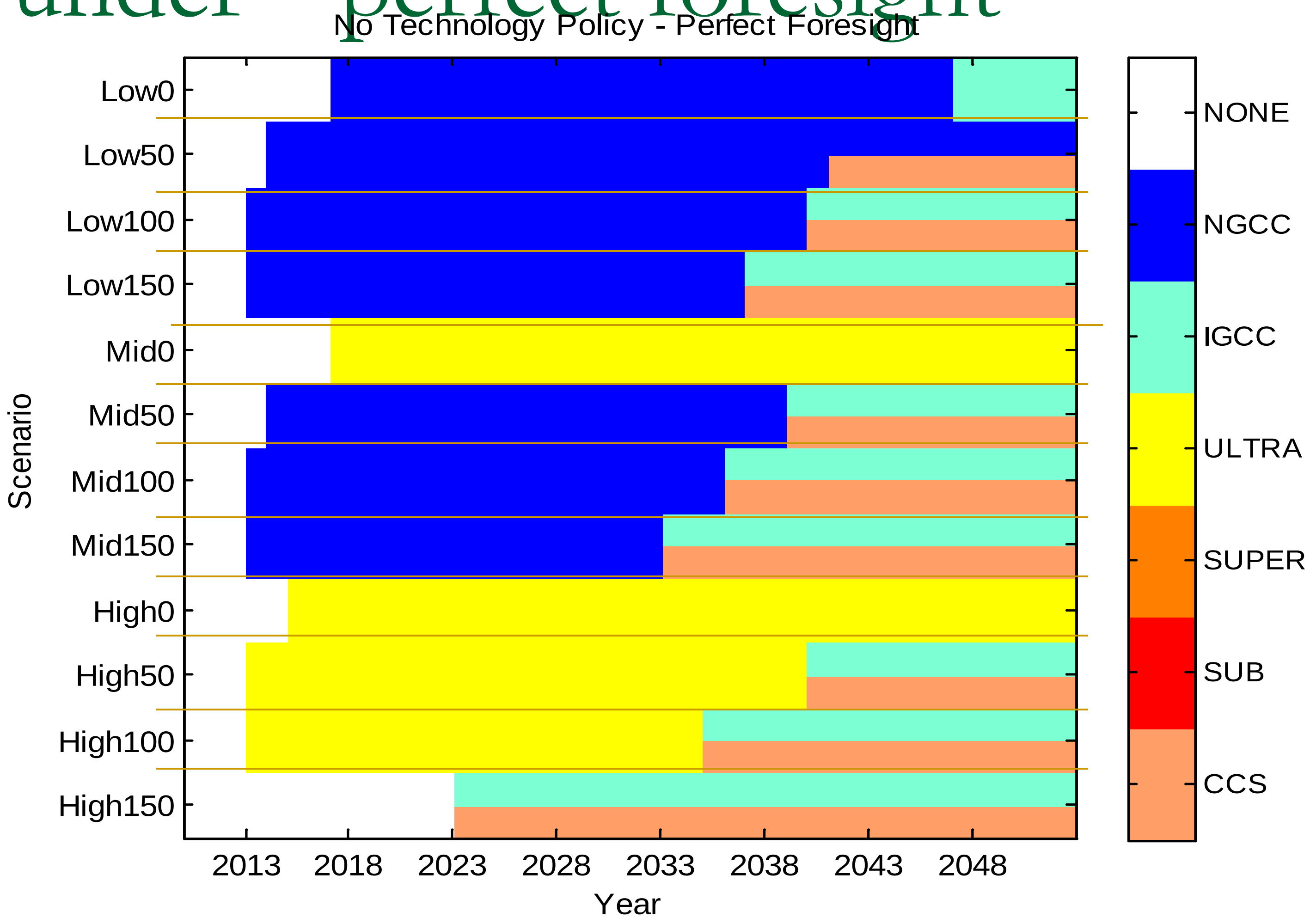
- Retrofits can only happen on available configuration

Optimization Model - Constraints

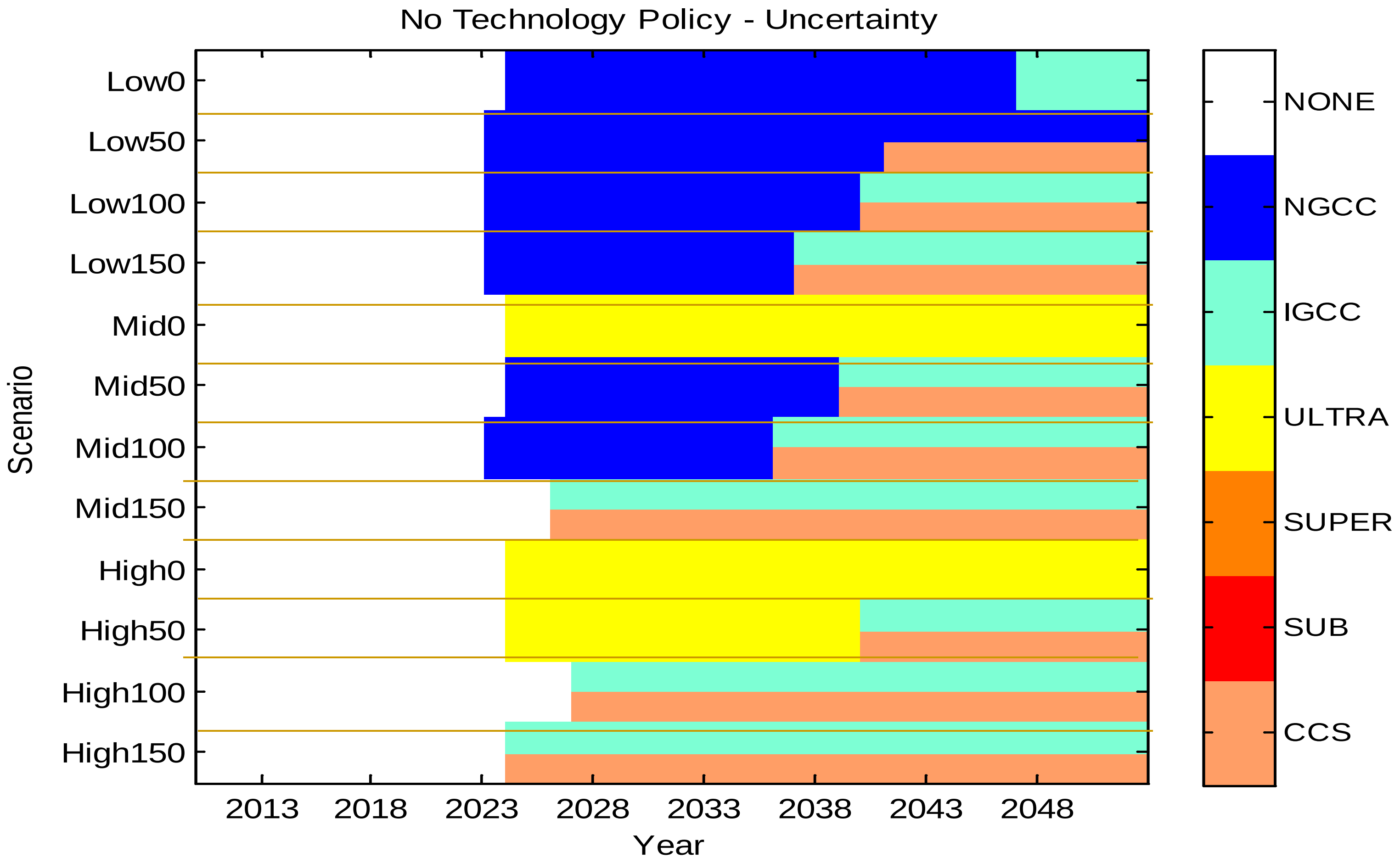
- Policy Tool # 1
  - New investments need to meet CO_2 emissions rate standard
- Policy Tool # 2
  - New investments that do not meet CO_2 standard pay surcharge
- Policy Tool # 3
  - Annual surcharge goes to escrow account
  - Money in escrow account can be recovered when
    - plant is retrofitted with CCS
    - Plant is replaced with a new plant + CCS
    - Max amount that can be withdrawn = capital cost of retrofit or new ccs plant

Results

Baseline policy: Technologies used under ~perfect foresight

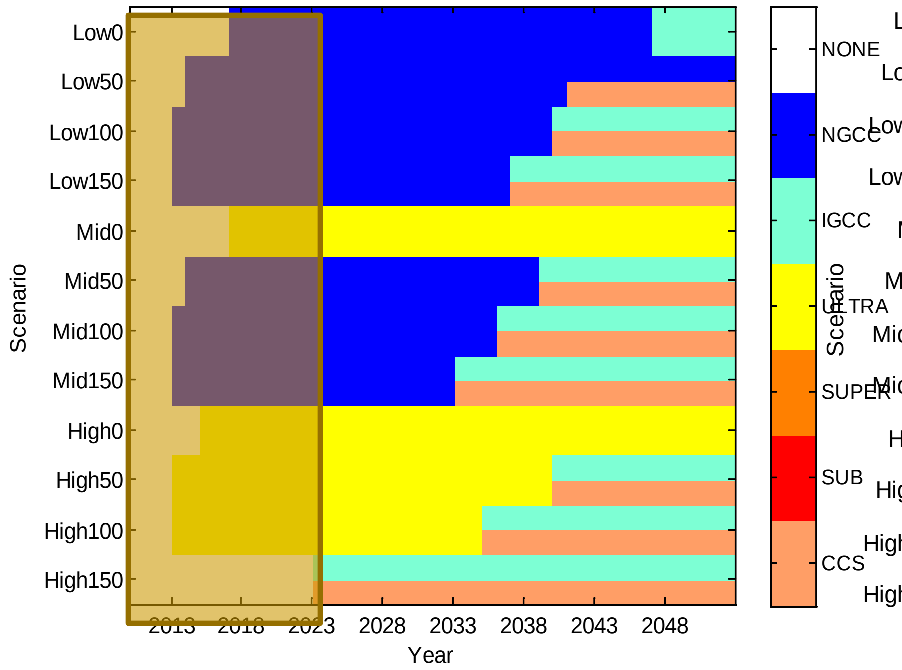


Baseline policy: technologies used under uncertainty

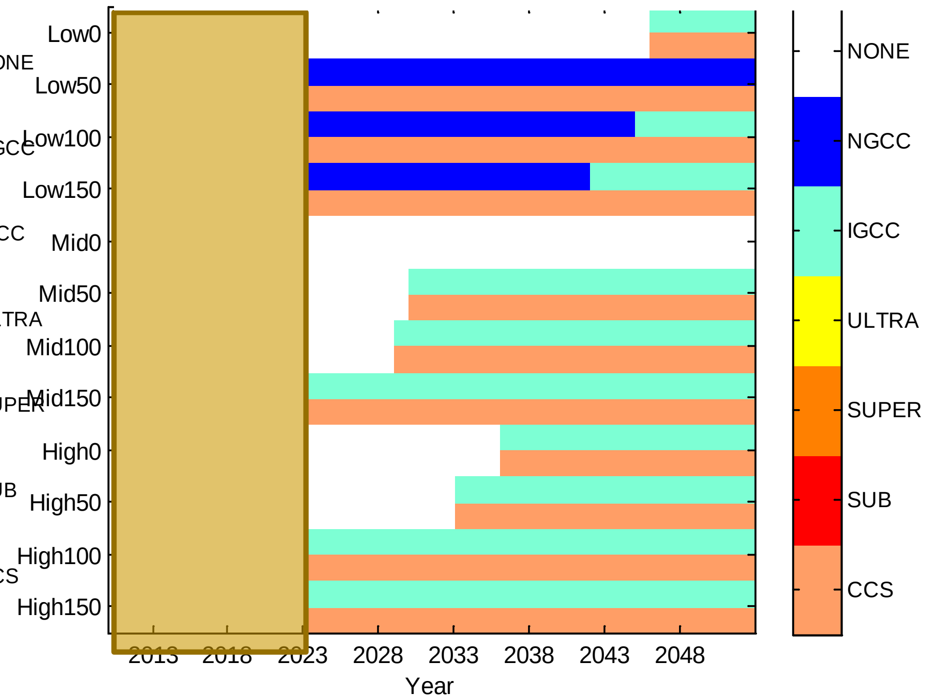


Effects of inflexible standard – ~perfect foresight

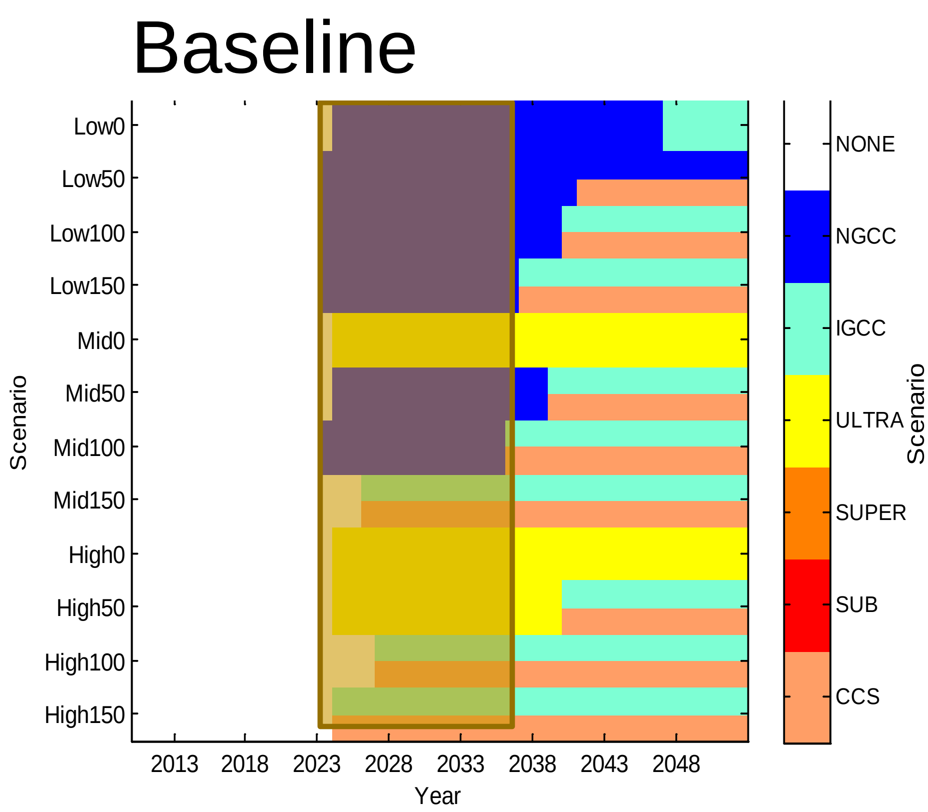
Baseline

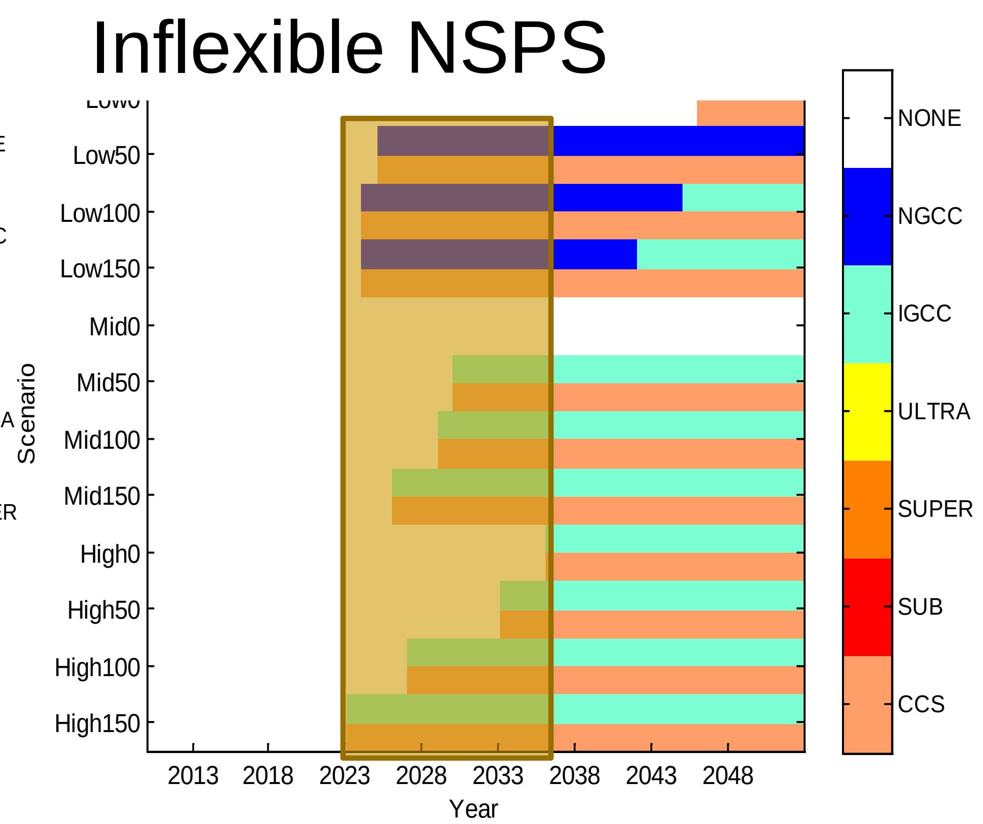


Inflexible NSPS



Effects of inflexible standard – Uncertainty





Defining **beta star** for policies 2 and 3

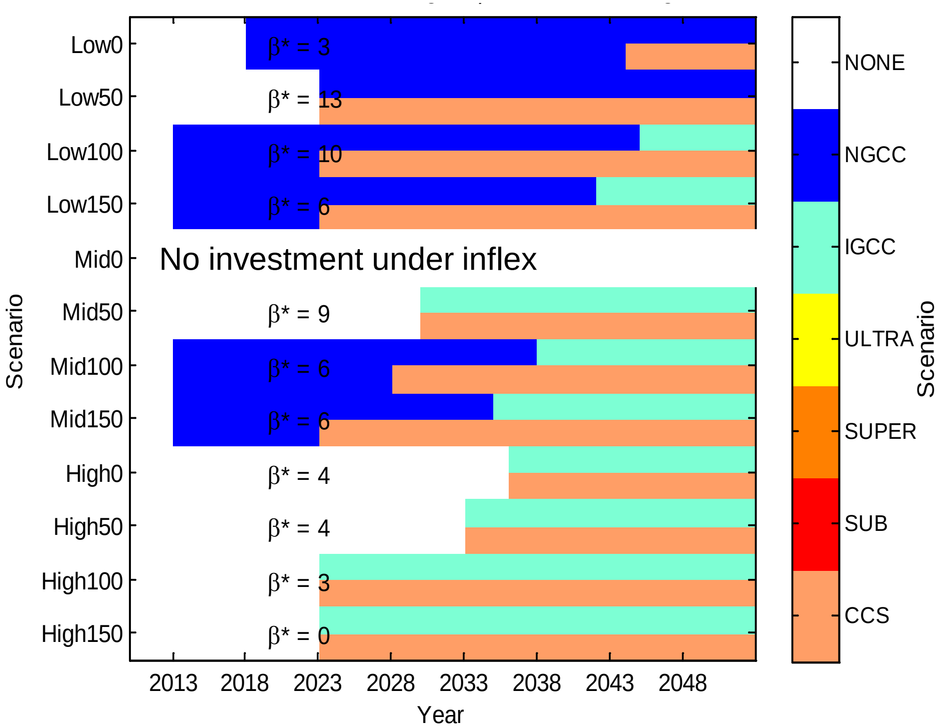
β* : Minimum surcharge ($/ton CO_2) that causes installation of CCS the same year or before than under the inflexible NSPS

- β* = 0 means
  - Baseline policy causes the same investment than inflex NSPS (like scenario 12)
  - There is no investment under inflex, so no need for a beta to beat this
- For a few scenarios β* < $14/ton does not exist (need to try higher values)

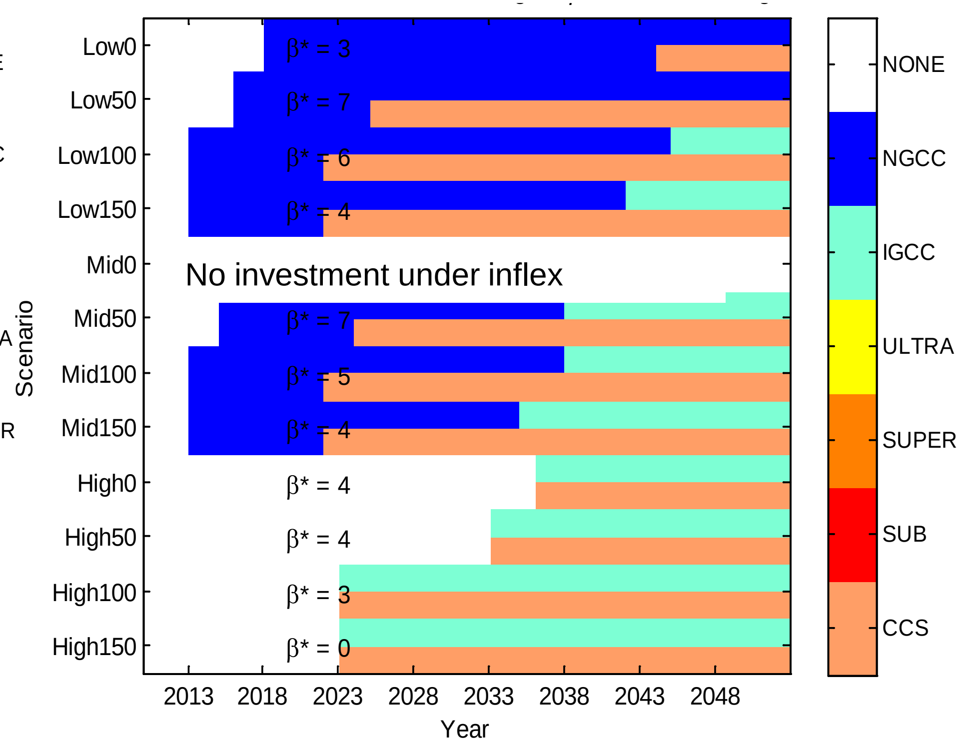
Policies 2 and 3 - ~perfect foresight

Both policies accelerate investment compared to inflex
Flex + escrow has lower beta than flex for some scenarios

Flex standard



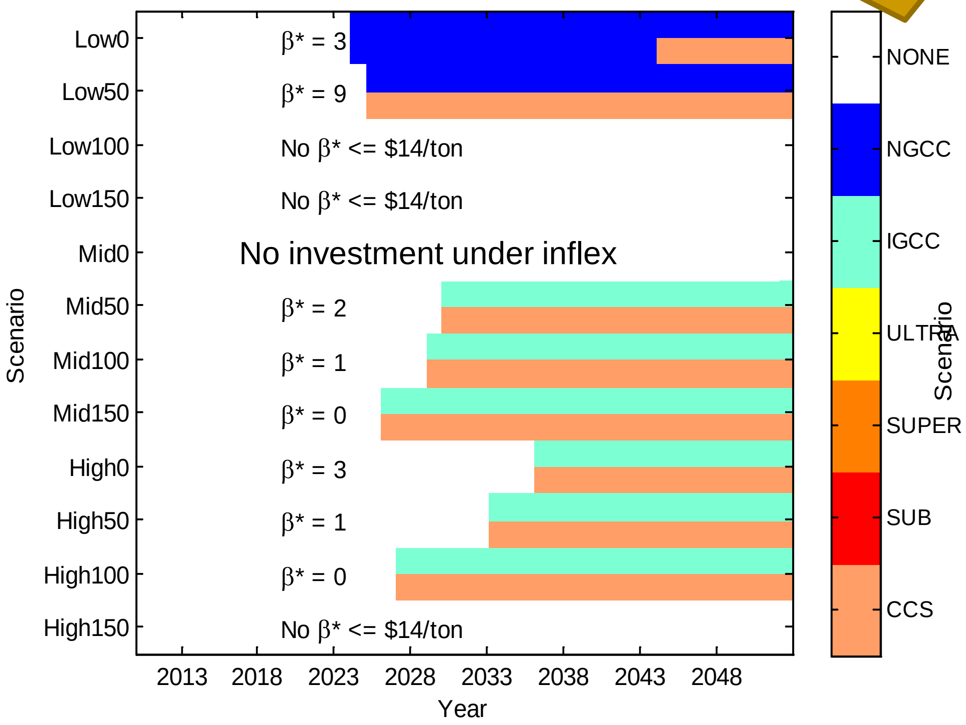
Flex + escrow



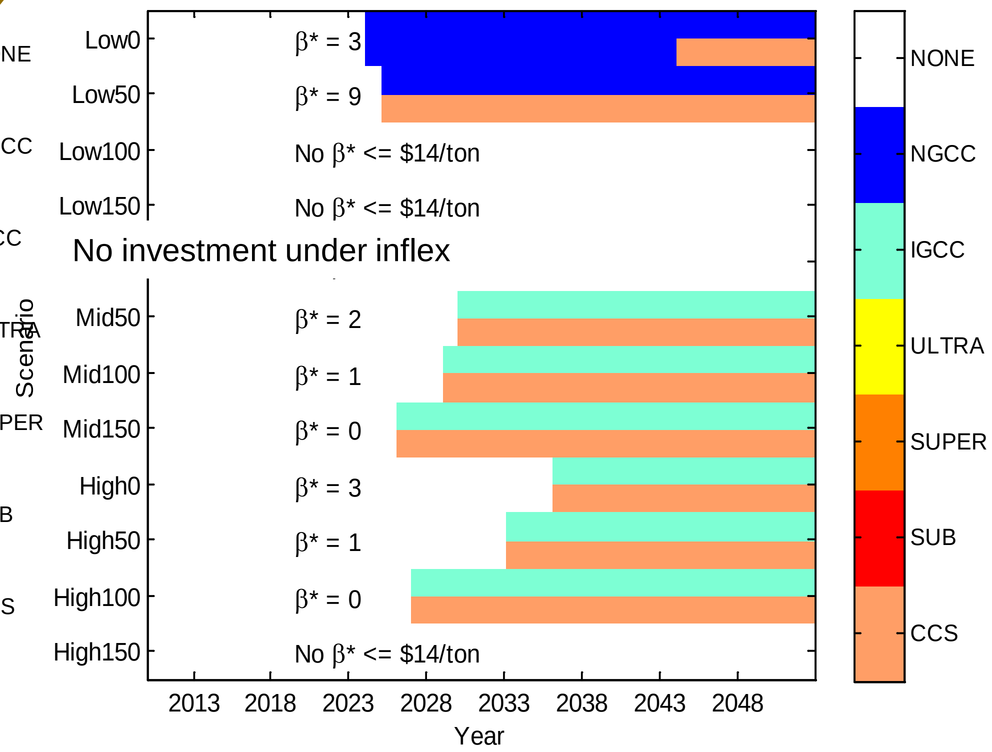
Policies 2 and 3 - ~uncertainty

No differences under uncertainty

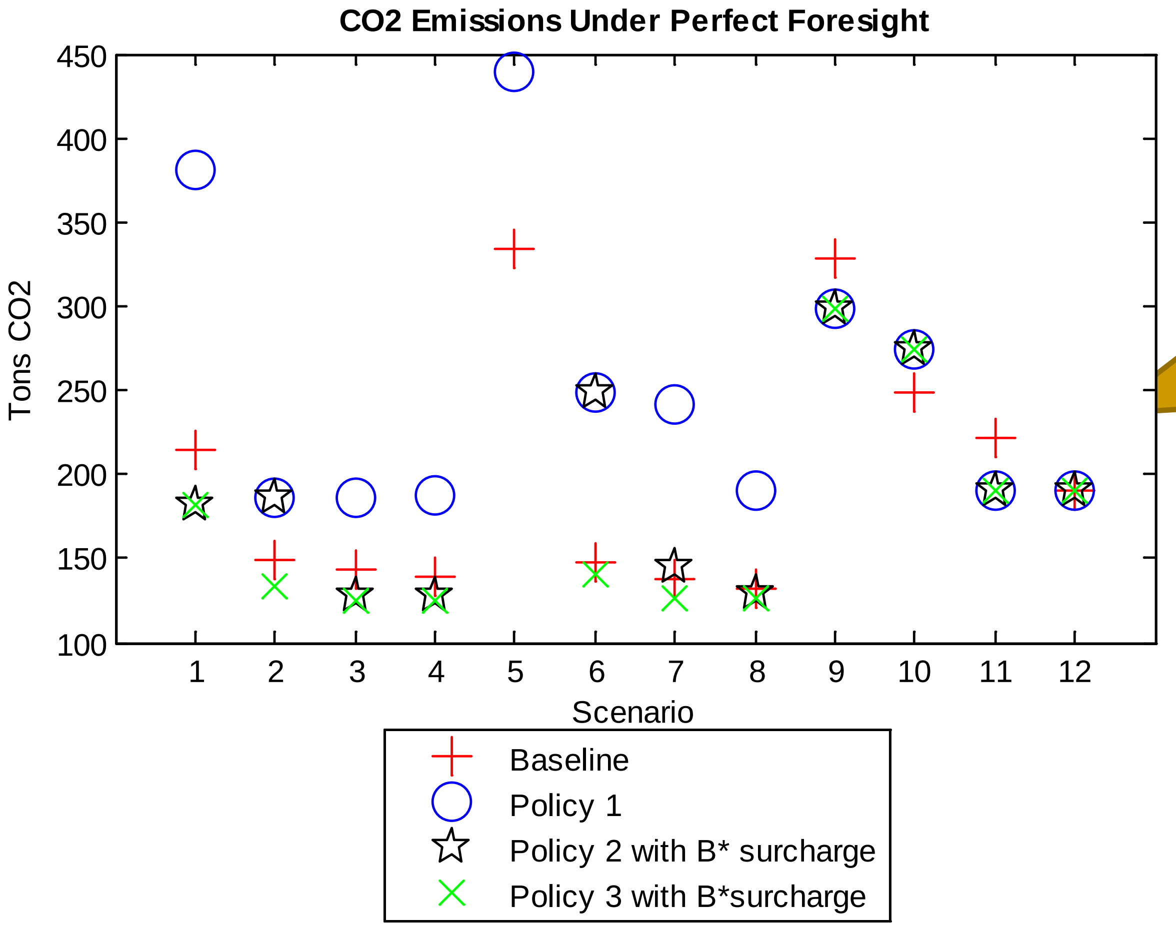
Flex standard



Flex + escrow

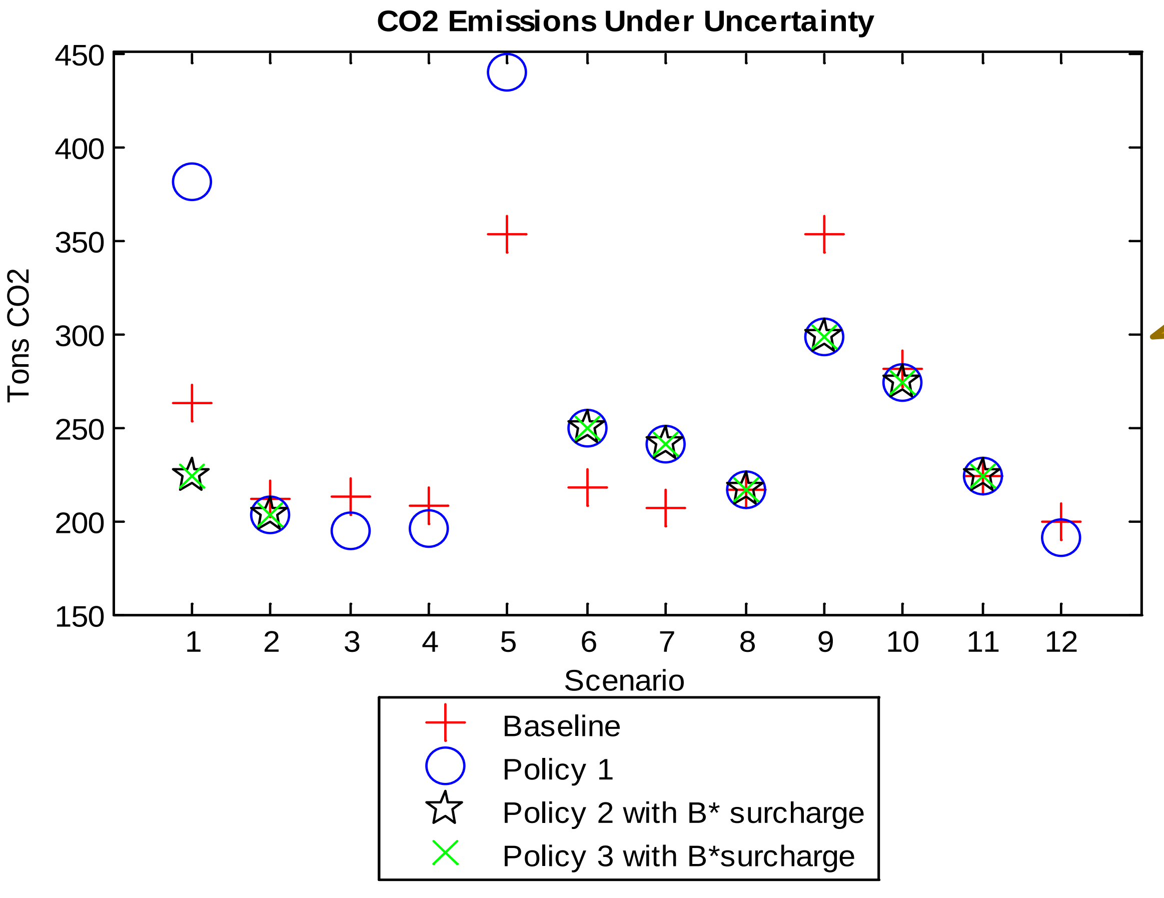


CO_2 emissions under perfect foresight



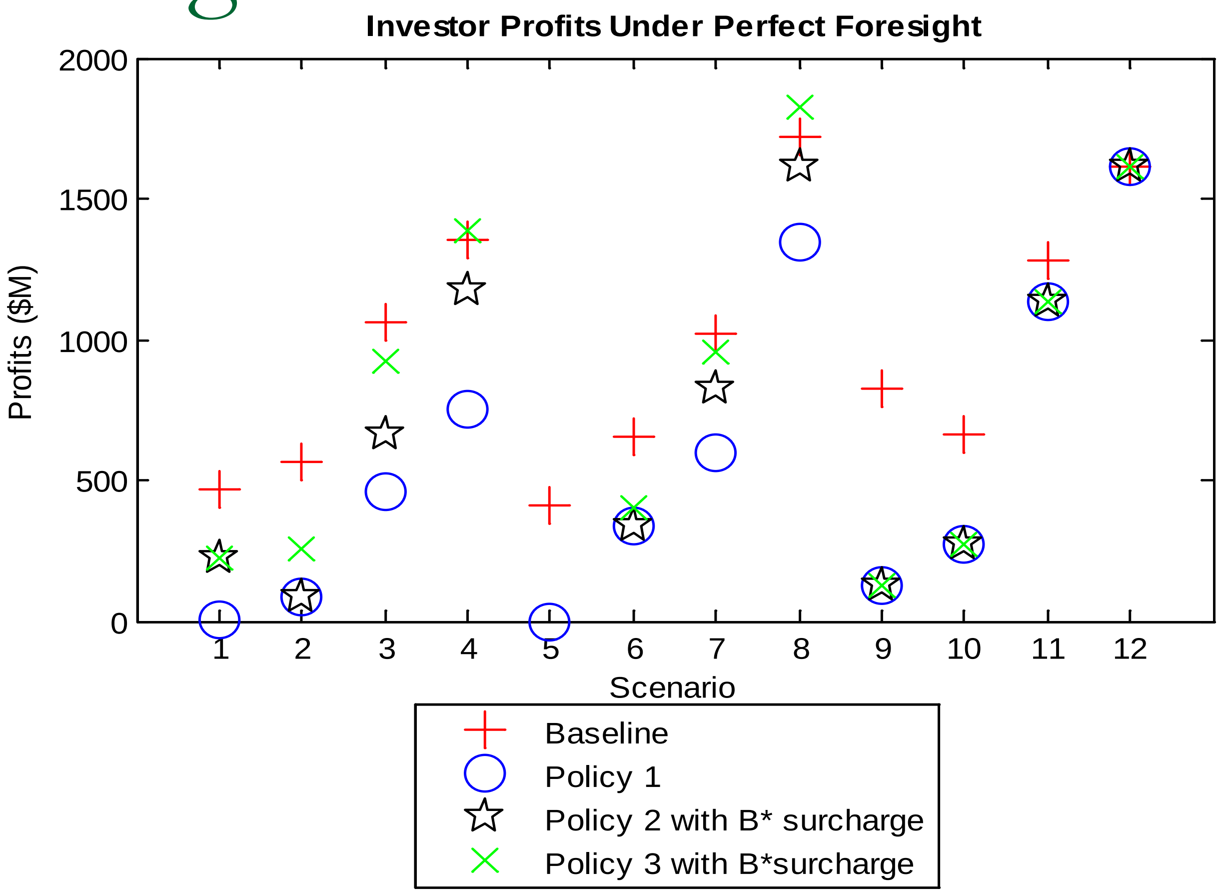
CO_2 emissions for policies 2 and 3 are never higher than under policy 1

CO_2 emissions under uncertainty



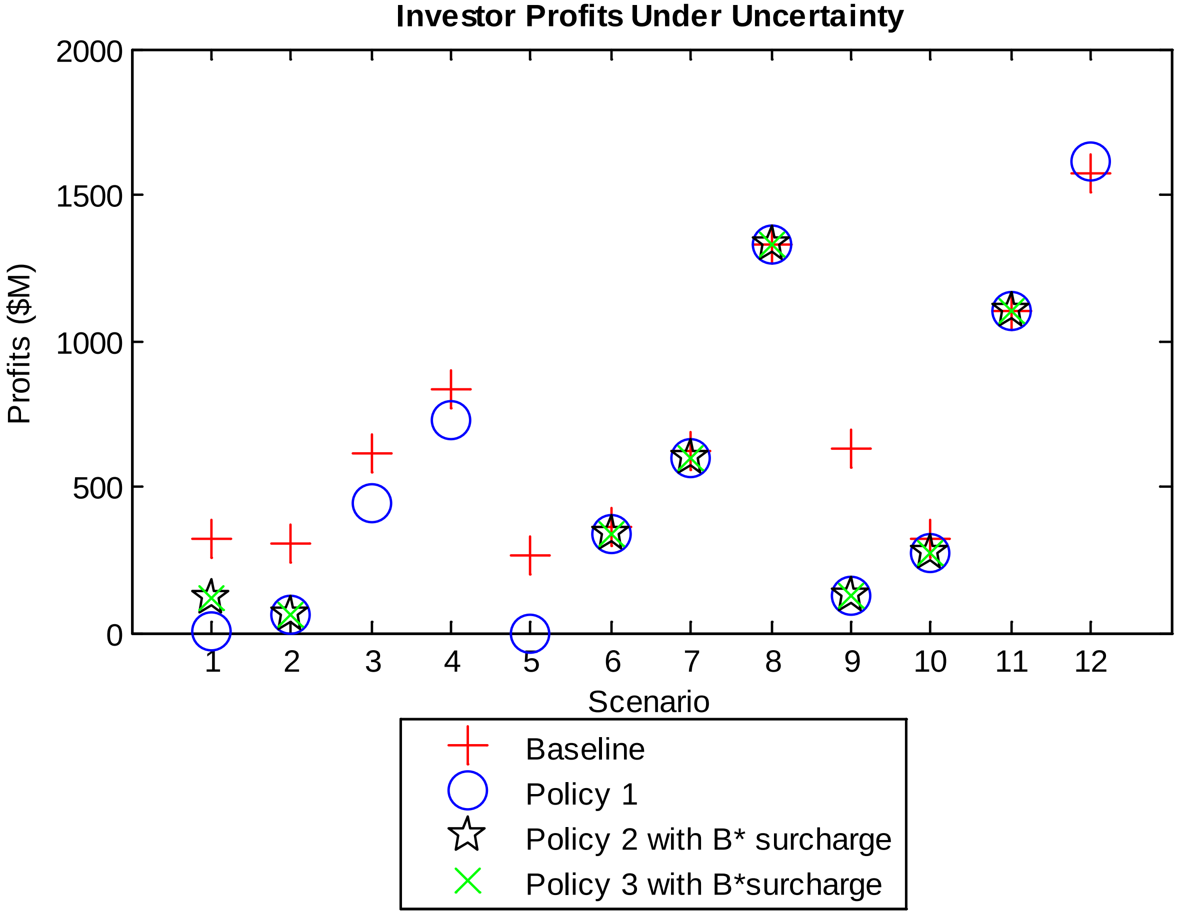
CO2 emissions for policies 2 and 3 are never higher than under policy 1

Investor's profits under ~perfect foresight



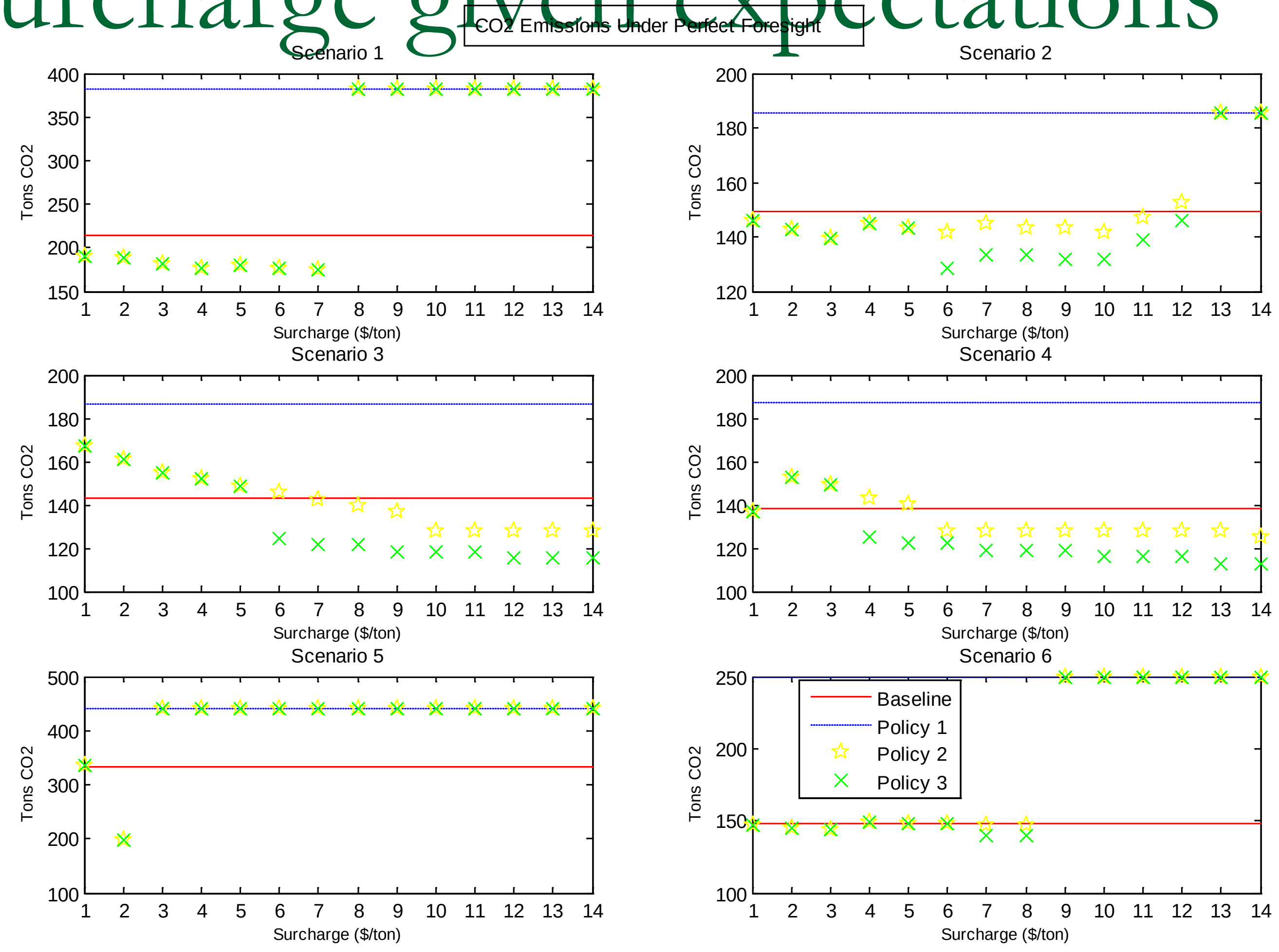
Profits for policies 2 and 3 are never worse than under policy 1

Investor's profits under uncertainty



Profits under policies 2 and 3 are never worse than under policy 1

Future work: Regulator's choice of surcharge given expectations



Conclusions:

- Incorporating flexibility into a technology standard does not delay and in fact could advance the timing of investment in new more efficient generation technology (coal or gas)

- Flexibility (with surcharge above a critical value) does not delay CCS investment. Time of installation depends on:
  - Stringency of CAT system (CO2 price)
  - NG prices
  - CO_2 emissions surcharge

- Policy with escrow fund can accelerate the date of installation of CCS. It depends on the size of the surcharge, the return on the fund, the rules, and the expectations on technological advance on CCS

- Flexibility does not lower investor's profits with respect to inflexible standard

Conclusions (2):

- Flexible mechanism is more likely to affect investment decisions for low CO_2 prices

Many questions still open

- How to choose the value of beta?
  - If low → does not replicate inflexible NSPS (looks like baseline)
  - if high → becomes as inflexible NSPS

- What to do with the surcharge revenues?

Thank you!

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Model:

c

Optimization Model - Formulation

Index	Description	Range
c	Investment or configuration. Type of plant and/or controls being installed and/or used	$0 \le c \le 15$
t	Current time period	$1 \le t \le 12$
τ	Time period in the future	$t < \tau \le t + 30$
f	Fuel	Coal, natural gas
p	Pollutants	SO_2, NO_x, Hg, CO_2
S	Regulatory scenarios	12 scenarios on Federal Policy and NG Prices

Decision Variables (First Stage)

$i_{c,t}$	Investment indicator. = 1 if there is an investment to install configuration c at time t	Binary
$u_{c,t}$	Utilization indicator. =1 if configuration c is used at time t.	Binary

Decision variables (Posterior stages)

Decision Variables (Posterior Stage)	Description	Variable type and range
$i_{c,\tau,s}$	Investment indicator. = 1 if there is an investment to install configuration *c* at time *t* under scenario s	Binary
$u_{c,\tau,s}$	Utilization indicator. =1 if configuration c is used at time *t* under scenario *s*	Binary

P A R A M E T E R S

$k_{c,t}$	Capital costs of installing configuration at time	$
$m_{c,t}$	Operating and maintenance costs of running configuration c at time t (not including fuel or electricity)	$
w_c	Quantity of electricity produced by configuration c	MWh/year
o_t	Price of electricity at time	$/MWh
$q_{c,f}$	Quantity of fuel f used by configuration c	MBTU/year
$n_{f,t}$	Price of fuel at time t	$/MBTU
$e_{p,c}$	Emissions of pollutant p by configuration c	Tons/year for SO2, NOx, CO2 Lbs/year for mercury
$a_{p,t}$	Price of emissions allowances for pollutant p at time t	$/ton for SO2, NOx, XO2 $/lb for mercury
b	CO2 emissions standard	tons
β_t	CO2 emissions surcharge at time , under flexible NSPS at time t	$/ton CO2
Π_s	Probability of scenario s	

Other variables – For Policy Tool 3

Intermediate decision variables	Description	Variable type and range
$TotalFunds_{s,t}$	Total amount of money deposited in the escrow fund under scenario s at time t	Real. $0 \le TotalFunds_{s,t} \le \sum_t \beta_t \left(CO2Emissions_t - b\right)$
$UsableFunds_{s,\tau}$	Funds recovered from the escrow account and used to offset capital costs of CCS, under scenario s at time future time tao	$0 \le UsableFunds_{s,t} \le TotalFunds_{s,t}$

Optimization problem

Minimize $f(i_{c,t,}, u_{c,t}, i_{c,\tau,s}, u_{c,\tau,s}) =$

$$\sum_c \left[k_{c,t} i_{c,t} + \left(m_{c,t} - w_c o_t + \sum_f q_{c,f} n_{f,t} + \sum_p e_{c,p} a_{p,t} + Max\left[e_{c,CO2} - b, 0 \right] \beta \right) u_{c,t} \right] - UsableFunds_t$$

$$+ \sum_s \pi_s \left[\sum_{\tau=t+1}^{t+T} (1+r)^{-\tau} \left[\sum_c k_{c,\tau,s} i_{c,\tau,s} + \left(m_{c,\tau} - w_c \tilde{o}_{\tau,s} + \sum_f q_{c,f} \tilde{n}_{f,\tau,s} + \sum_p e_{c,p} \tilde{a}_{p,\tau,s} + Max\left[e_{c,CO2} - b, 0 \right] \beta \right) u_{c,\tau,s} \right] - UsableFunds_{s,\tau} \right]$$

Characterize uncertainty with discrete probabilities

At year *t* the probability assigned to any of the twelve scenarios other than the current scenario (*j*) is

$$p_t^{\bar{j}} = \frac{1}{12} \times \left(\frac{2020 - t}{2020 - 2007} \right)$$

and the probability assigned to scenario *j* is

$$p_t^{j} = 1 - \frac{11}{12} \times \left(\frac{2020 - t}{2020 - 2007} \right)$$