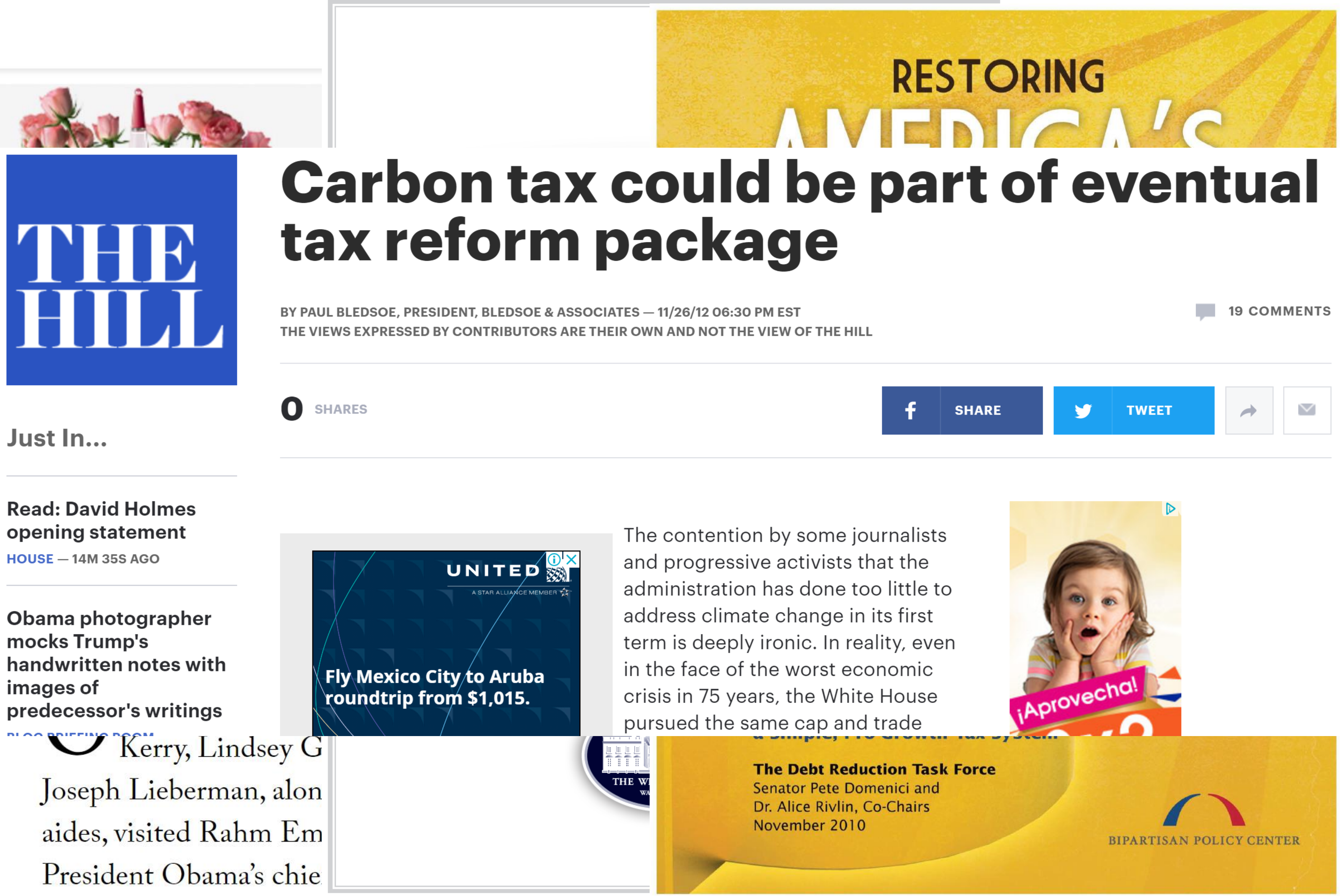
Using Carbon Taxes to Meet an Emissions Target – Why and How

Billy Pizer and Bobby Harris

Sanford School and Nicholas Institute

Duke University

New interest in a carbon tax (2010)



RESTORING AMERICA'S

Carbon tax could be part of eventual tax reform package

BY PAUL BLEDSOE, PRESIDENT, BLEDSOE & ASSOCIATES — 11/26/12 06:30 PM EST
THE VIEWS EXPRESSED BY CONTRIBUTORS ARE THEIR OWN AND NOT THE VIEW OF THE HILL

19 COMMENTS

0 SHARES

SHARE TWEET

The contention by some journalists and progressive activists that the administration has done too little to address climate change in its first term is deeply ironic. In reality, even in the face of the worst economic crisis in 75 years, the White House pursued the same cap and trade

Kerry, Lindsey G
Joseph Lieberman, alon
aides, visited Rahm Em
President Obama's chie

The Debt Reduction Task Force
Senator Pete Domenici and
Dr. Alice Rivlin, Co-Chairs
November 2010

BIPARTISAN POLICY CENTER

New interest in a carbon tax (2017)

CLIMATE LEADERSHIP COUNCIL

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OUR PLAN

- THE FOUR PILLARS
- ORIGINAL CO-AUTHORS
- WHY CLIMATE PROGRESS IS DEADLOCKED
- ADVANTAGES OF A CARBON DIVIDENDS PLAN
- THE RIGHT STRATEGY FOR OUR POLITICAL MOMENT

THE FOUR PILLARS OF OUR CARBON DIVIDENDS PLAN

I. A GRADUALLY RISING CARBON FEE

Economists agree that an escalating carbon fee offers the most cost-effective climate policy solution, sending a powerful price signal to steer businesses and consumers towards a low-carbon future. Accordingly, the first pillar of our bipartisan plan is an economy-wide fee on CO_2 emissions starting at $40 a ton (2017$) and increasing every year at 5% above inflation. If implemented in 2021, this will cut U.S. CO_2 emissions in half by 2035 (as compared to 2005) and far exceed the U.S. Paris commitment. To ensure these targets are met, an Emissions Assurance Mechanism will temporarily increase the fee faster if key reduction benchmarks are not achieved.

II. CARBON DIVIDENDS FOR ALL AMERICANS

All net proceeds from the carbon fee will be returned to the American people on an equal and quarterly basis. A family of four will receive approximately $2,000 in carbon dividend payments in the first year. This amount will grow as the carbon fee increases, creating a positive feedback loop: the more the climate is protected, the greater the dividend payments to all Americans. According to the U.S. Department of the Treasury, the vast majority of American families will receive more in carbon dividends than they pay in increased energy costs. The popularity of dividends will help ensure the longevity of a bipartisan grand bargain based on these pillars.

III. SIGNIFICANT REGULATORY SIMPLIFICATION

The third pillar is the streamlining of regulations that are no longer necessary upon the enactment of a rising carbon fee. In the majority of cases where a carbon fee offers a more cost-effective solution, the fee will replace regulations. All current and future federal stationary source carbon regulations, for example, would be displaced or preempted. This regulatory simplification will be contingent on the continued presence of an ambitious carbon fee. Trading regulations for a carbon price will promote economic growth and offer companies the certainty and flexibility they need to innovate and make long-term investments in a low-carbon future.

Why? Environmental groups want more

EDF ENVIRONMENTAL DEFENSE FUND®
Finding the ways that work

What to Look For in Proposed Climate Change Solutions

Federal legislation to help the United State achieve net-zero climate pollution by 2050 – that is, adding no more carbon emissions to the atmosphere than we can remove – must lock in pollution reductions, grow the economy, and protect vulnerable populations.

To do all that, while providing communities everywhere with access to clean, reliable, affordable energy, we need to harness the power of markets to drive investment, create jobs, spur innovation, and deliver the transformative change needed to build the clean energy economy.

We know such policies work, because we've tried them before. Flexible policies that set firm, declining limits on pollution and let businesses find the best ways to respond have helped meet environmental goals faster and more cheaply than expected. We can do this while growing the economy by limiting pollution and rewarding new and better ways to cut pollution.

Performance-based policy and environmental integrity

The most straightforward way to cut carbon is to put a **clear enforceable limit on pollution** that guarantees the environmental outcome, while giving businesses flexibility to determine the best way to meet that limit. Ten U.S. states already have successful programs in place that take exactly this approach, and several others are moving in that direction.

Another approach, a **carbon fee**, also charges companies for polluting. But making companies pay for their pollution doesn't guarantee how much pollution they will cut. So for a fee to be effective, it must include an **"environmental integrity mechanism" (EIM)** or an environmental backstop that ties the fee to performance — and adjusts it, as necessary, to keep us on track to meet our environmental goals.

Harvard Environmental Law Review

Resolving the Inherent Uncertainty of Carbon Taxes

June 19, 2017 by

Search the site ...

Carbon taxes are a critical regulatory mechanism for reducing greenhouse gas emissions. A carbon tax directly sets a price on emissions, either as an output tax on producers of fossil fuels (coal, petroleum products, and natural gas) or a tax on the purchase of fossil fuels. Such a tax makes the carbon price certain, but the total emissions that ultimately result from the policy are uncertain. This trade-off between price certainty and emissions certainty has important environmental, economic, and political

HARV.

COST CONTAINMENT IN CLIMATE CHANGE POLICY: ALTERNATIVE APPROACHES TO MITIGATING PRICE VOLATILITY

Gilbert E. Metcalf[*]

ABSTRACT

Cap-and-trade systems are emerging as the front-running policy choice to address climate change concerns in many countries. One of the apparent attractions of this approach is the ability to achieve hard limits on emissions over a control period. The cost of achieving this certainty on emission limits is price volatility. I discuss and evaluate various approaches within cap-and-trade systems to reduce price volatility. A fundamental tradeoff exists between certainty of emission limits and price volatility. A pure carbon tax sacrifices certainty of emission limits in favor of price stability. I discuss how a hybrid carbon tax can be designed to achieve a balance between price stability and emissions certainty. This hybrid, dubbed the Responsive Emissions Autonomous Carbon Tax (REACT), combines the short-run price stability of a carbon tax with the long-run certainty of emission reductions over a control period.

29 VA. TAX REV. 381 (2009)

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Winter 2020
Cover image

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EISSN 1750-6824

< Previous

SYMPOSIUM: ADDING MITIGATION CERTAINTY TO A U.S. CARBON TAX

EDITOR'S CHOICE

The Political Economy of Hybrid Approaches to a U.S. Carbon Tax: A Perspective from the Policy World

Susanne A Brooks, Nathaniel O Keohane

Rev Environ Econ Policy, Volume 14, Issue 1, Winter 2020, Pages 67–75,
https://doi.org/10.1093/reep/rez022

Abstract ▼ View article

EDITOR'S CHOICE

Carbon Tax Review and Updating: Institutionalizing an Act-Learn-Act Approach to U.S. Climate Policy FREE

Joseph E Aldy

Rev Environ Econ Policy, Volume 14, Issue 1, Winter 2020, Pages 76–94,
https://doi.org/10.1093/reep/rez019

Abstract ▼ View article Supplementary data

EDITOR'S CHOICE

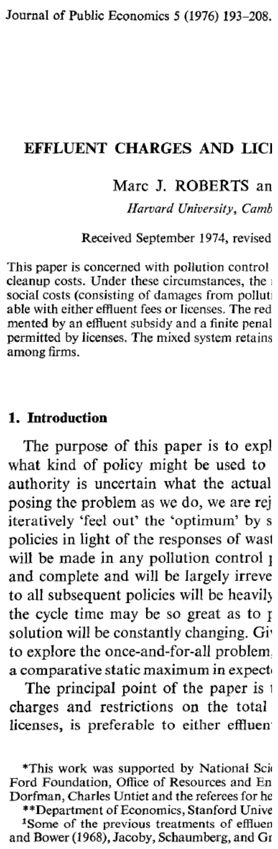
Designing and Evaluating a U.S. Carbon Tax Adjustment Mechanism to Reduce Emissions Uncertainty FREE

Marc A C Hafstead, Roberton C Williams, III

Rev Environ Econ Policy, Volume 14, Issue 1, Winter 2020, Pages 95–113,
https://doi.org/10.1093/reep/rez018

Abstract ▼ View article

Long history of writing about cap and trade with price ceilings and floors


Journal of Public Economics 5 (1976) 193–208.

EFFLUENT CHARGES AND LIC

Marc J. ROBERTS an

Harvard University, Camb

Received September 1974, revised

This paper is concerned with pollution control
cleanup costs. Under these circumstances, the
social costs (consisting of damages from polluti
able with either effluent fees or licenses. The red
mented by an effluent subsidy and a finite penal
permitted by licenses. The mixed system retains
among firms.

1. Introduction

The purpose of this paper is to expl
what kind of policy might be used to
authority is uncertain what the actual
posing the problem as we do, we are rej
iteratively 'feel out' the 'optimum' by s
policies in light of the responses of wast
will be made in any pollution control
and complete and will be largely irreve
to all subsequent policies will be heavily
the cycle time may be so great as to
solution will be constantly changing. Gi
to explore the once-and-for-all problem
a comparative static maximum in expect
The principal point of the paper is
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*This work was supported by National Sci
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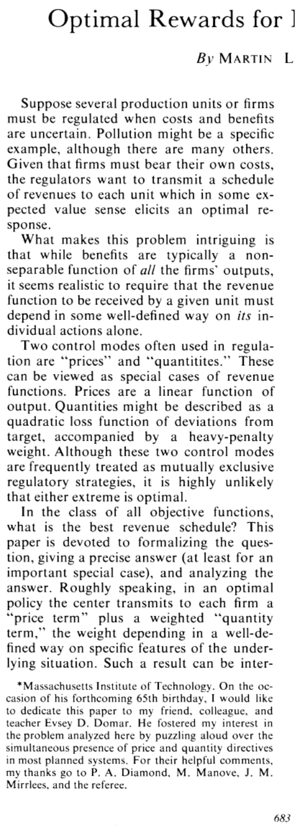
Optimal Rewards for

By MARTIN L

Suppose several production units or firms must be regulated when costs and benefits are uncertain. Pollution might be a specific example, although there are many others. Given that firms must bear their own costs, the regulators want to transmit a schedule of revenues to each unit which in some expected value sense elicits an optimal response.

What makes this problem intriguing is that while benefits are typically a nonseparable function of *all* the firms' outputs, it seems realistic to require that the revenue function to be received by a given unit must depend in some well-defined way on *its* individual actions alone.

Two control modes often used in regulation are "prices" and "quantities." These can be viewed as special cases of revenue functions. Prices are a linear function of output. Quantities might be described as a quadratic loss function of deviations from target, accompanied by a heavy-penalty weight. Although these two control modes are frequently treated as mutually exclusive regulatory strategies, it is highly unlikely that either extreme is optimal.

In the class of all objective functions, what is the best revenue schedule? This paper is devoted to formalizing the question, giving a precise answer (at least for an important special case), and analyzing the answer. Roughly speaking, in an optimal policy the center transmits to each firm a "price term" plus a weighted "quantity term," the weight depending in a well-defined way on specific features of the underlying situation. Such a result can be inter-

*Massachusetts Institute of Technology. On the occasion of his forthcoming 65th birthday, I would like to dedicate this paper to my friend, colleague, and teacher Evsey D. Domar. He fostered my interest in the problem analyzed here by puzzling aloud over the simultaneous presence of price and quantity directives in most planned systems. For their helpful comments, my thanks go to P. A. Diamond, M. Manove, J. M. Mirrlees, and the referee.

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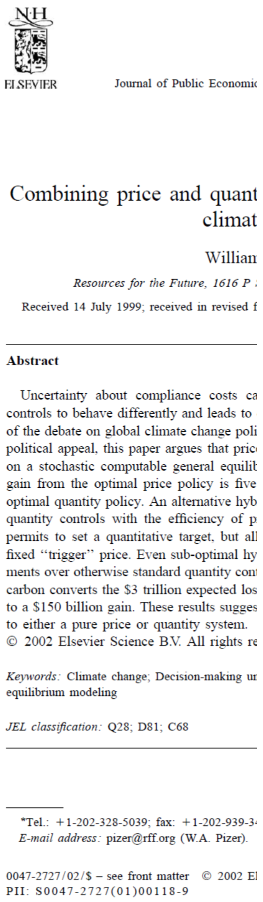
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Journal of Public Economic

Combining price and quant
climat

Willian

Resources for the Future, 1616 P

Received 14 July 1999; received in revised f

Abstract

Uncertainty about compliance costs ca
controls to behave differently and leads to
of the debate on global climate change poli
political appeal, this paper argues that pric
on a stochastic computable general equilib
gain from the optimal price policy is five
optimal quantity policy. An alternative hyb
quantity controls with the efficiency of p
permits to set a quantitative target, but all
fixed "trigger" price. Even sub-optimal hy
ments over otherwise standard quantity con
carbon converts the $3 trillion expected los
to a $150 billion gain. These results sugges
to either a pure price or quantity system.
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Keywords: Climate change; Decision-making ur
equilibrium modeling

JEL classification: Q28; D81; C68

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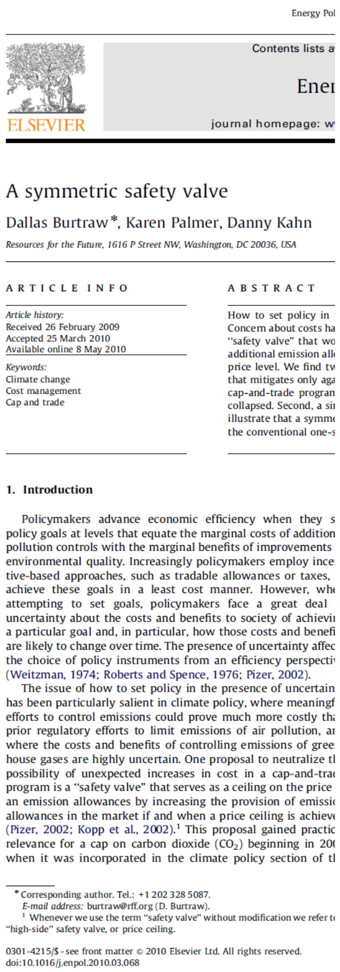
Energy Pol

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A symmetric safety valve

Dallas Burtraw*, Karen Palmer, Danny Kahn

Resources for the Future, 1616 P Street NW, Washington, DC 20036, USA

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Keywords:
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Cap and trade

ABSTRACT

How to set policy in
Concern about costs ha
"safety valve" that wo
additional emission all
price level. We find tw
that mitigates only aga
cap-and-trade program
collapsed. Second, a si
illustrate that a symme
the conventional one-s

1. Introduction

Policymakers advance economic efficiency when they s
policy goals at levels that equate the marginal costs of addition
pollution controls with the marginal benefits of improvements
environmental quality. Increasingly policymakers employ ince
tive-based approaches, such as tradable allowances or taxes,
achieve these goals in a least cost manner. However, whe
attempting to set goals, policymakers face a great deal
uncertainty about the costs and benefits to society of achievi
a particular goal and, in particular, how those costs and benefi
are likely to change over time. The presence of uncertainty affec
the choice of policy instruments from an efficiency perspectiv
(Weitzman, 1974; Roberts and Spence, 1976; Pizer, 2002).
The issue of how to set policy in the presence of uncertain
has been particularly salient in climate policy, where meaningf
efforts to control emissions could prove much more costly tha
prior regulatory efforts to limit emissions of air pollution, a
where the costs and benefits of controlling emissions of gree
house gases are highly uncertain. One proposal to neutralize t
possibility of unexpected increases in cost in a cap-and-tra
program is a "safety valve" that serves as a ceiling on the price
an emission allowances by increasing the provision of emissi
allowances in the market if and when a price ceiling is achiev
(Pizer, 2002; Kopp et al., 2002).[1] This proposal gained practic
relevance for a cap on carbon dioxide (CO_2) beginning in 20
when it was incorporated in the climate policy section of t

* Corresponding author. Tel.: +1 202 328 5087.
E-mail address: burtraw@rff.org (D. Burtraw).
[1] Whenever we use the term "safety valve" without modification we refer t
"high-side" safety valve, or price ceiling.

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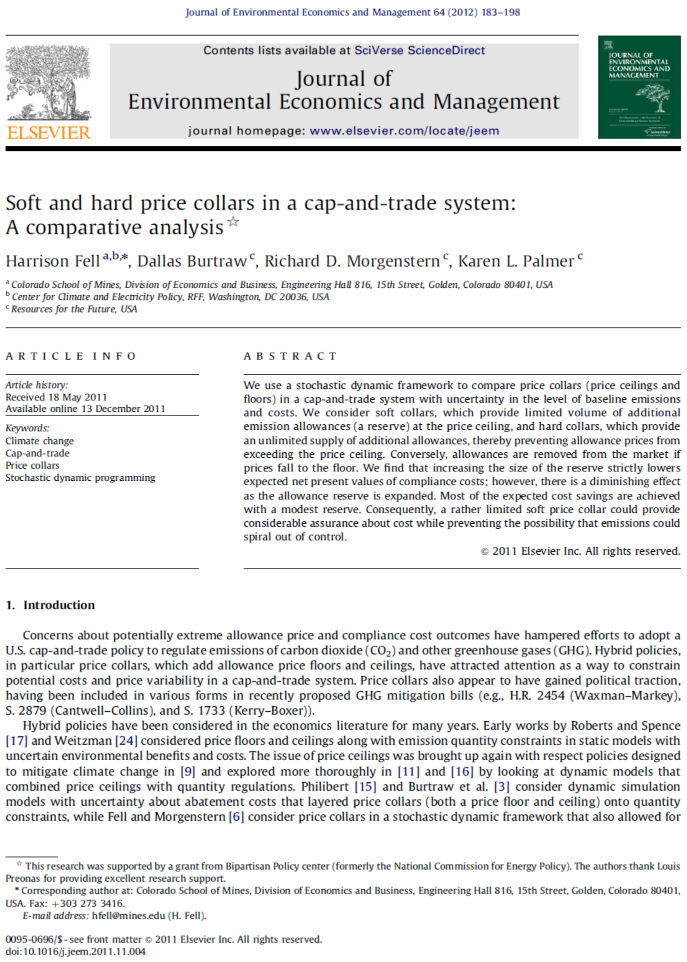
Journal of Environmental Economics and Management 64 (2012) 183–198

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Soft and hard price collars in a cap-and-trade system: A comparative analysis ☆

Harrison Fell [a,b,*], Dallas Burtraw [c], Richard D. Morgenstern [c], Karen L. Palmer [c]

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[c] *Resources for the Future, USA*

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ABSTRACT

We use a stochastic dynamic framework to compare price collars (price ceilings and floors) in a cap-and-trade system with uncertainty in the level of baseline emissions and costs. We consider soft collars, which provide limited volume of additional emission allowances (a reserve) at the price ceiling, and hard collars, which provide an unlimited supply of additional allowances, thereby preventing allowance prices from exceeding the price ceiling. Conversely, allowances are removed from the market if prices fall to the floor. We find that increasing the size of the reserve strictly lowers expected net present values of compliance costs; however, there is a diminishing effect as the allowance reserve is expanded. Most of the expected cost savings are achieved with a modest reserve. Consequently, a rather limited soft price collar could provide considerable assurance about cost while preventing the possibility that emissions could spiral out of control.

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1. Introduction

Concerns about potentially extreme allowance price and compliance cost outcomes have hampered efforts to adopt a U.S. cap-and-trade policy to regulate emissions of carbon dioxide (CO_2) and other greenhouse gases (GHG). Hybrid policies, in particular price collars, which add allowance price floors and ceilings, have attracted attention as a way to constrain potential costs and price variability in a cap-and-trade system. Price collars also appear to have gained political traction, having been included in various forms in recently proposed GHG mitigation bills (e.g., H.R. 2454 (Waxman–Markey), S. 2879 (Cantwell–Collins), and S. 1733 (Kerry–Boxer)).

Hybrid policies have been considered in the economics literature for many years. Early works by Roberts and Spence [17] and Weitzman [24] considered price floors and ceilings along with emission quantity constraints in static models with uncertain environmental benefits and costs. The issue of price ceilings was brought up again with respect policies designed to mitigate climate change in [9] and explored more thoroughly in [11] and [16] by looking at dynamic models that combined price ceilings with quantity regulations. Philibert [15] and Burtraw et al. [3] consider dynamic simulation models with uncertainty about abatement costs that layered price collars (both a price floor and ceiling) onto quantity constraints, while Fell and Morgenstern [6] consider price collars in a stochastic dynamic framework that also allowed for

☆ This research was supported by a grant from Bipartisan Policy center (formerly the National Commission for Energy Policy). The authors thank Louis Preonas for providing excellent research support.
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E-mail address: hfell@mines.edu (H. Fell).

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#1

Why focus on cap-and-trade with price collar?

- Practical. Easier to implement without centralized information.
  - Within a compliance period, conduct multiple auctions with a price floor.
  - Allow regulated firms to pay a fee in lieu of allowances.
  - Or, include tiered auctions at different reserve prices.
  - *Market actors do all the work.*
  - Tax requires collecting emission information and then make an adjustment. Do it well: model necessary adjustment (including seasonality and trends).
  - *Regulator does all the work.*

#2

Why focus on cap-and-trade with price collar?

- Political. We see these policies in practice

Cap and trade with price collar in practice

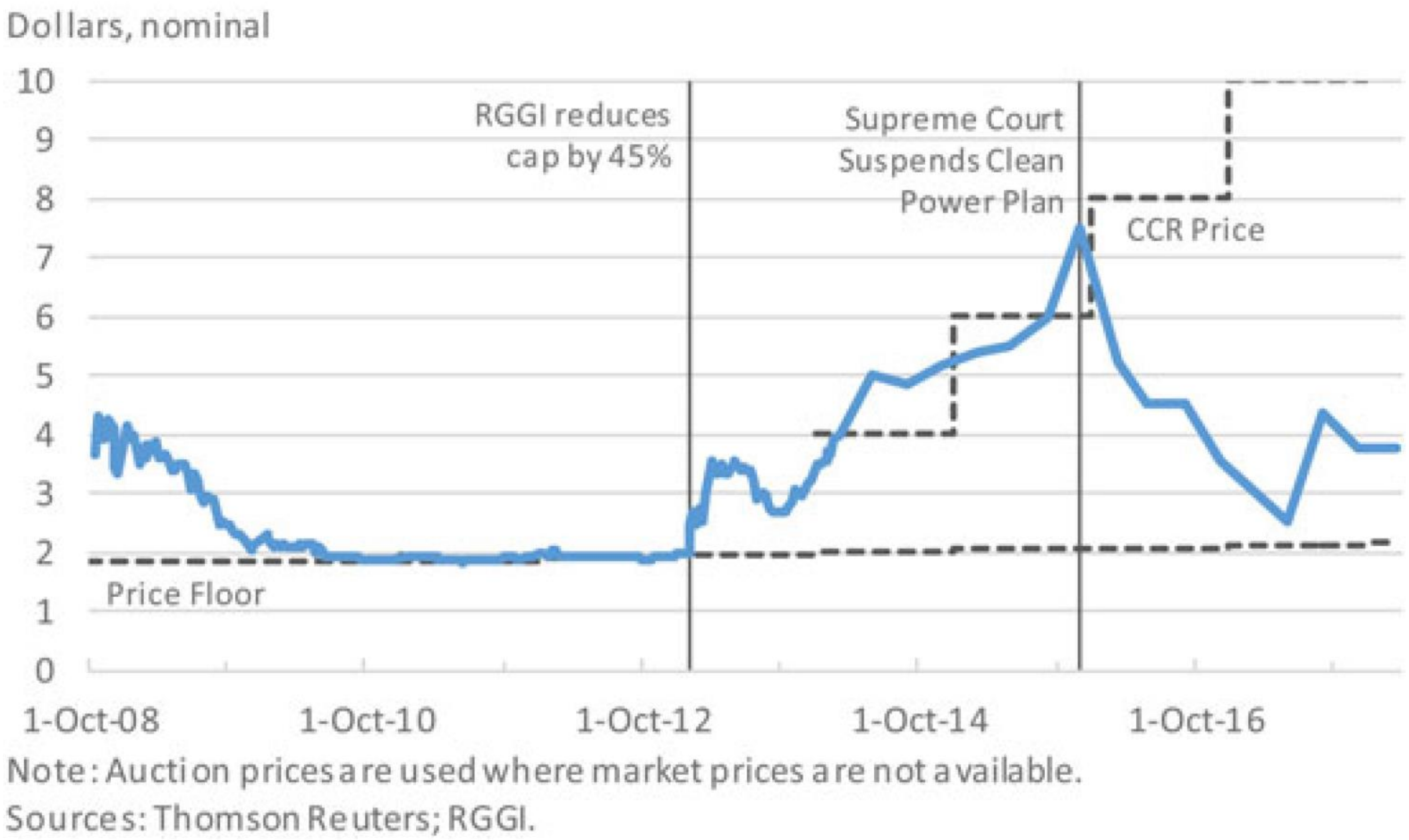


Figure 5. Prices in the Regional Greenhouse Gas Initiative carbon dioxide program

Source: Burtraw and Keyes (2018). *Agriculture and Resource Economics Review*.

Cap and trade with price collar in practice

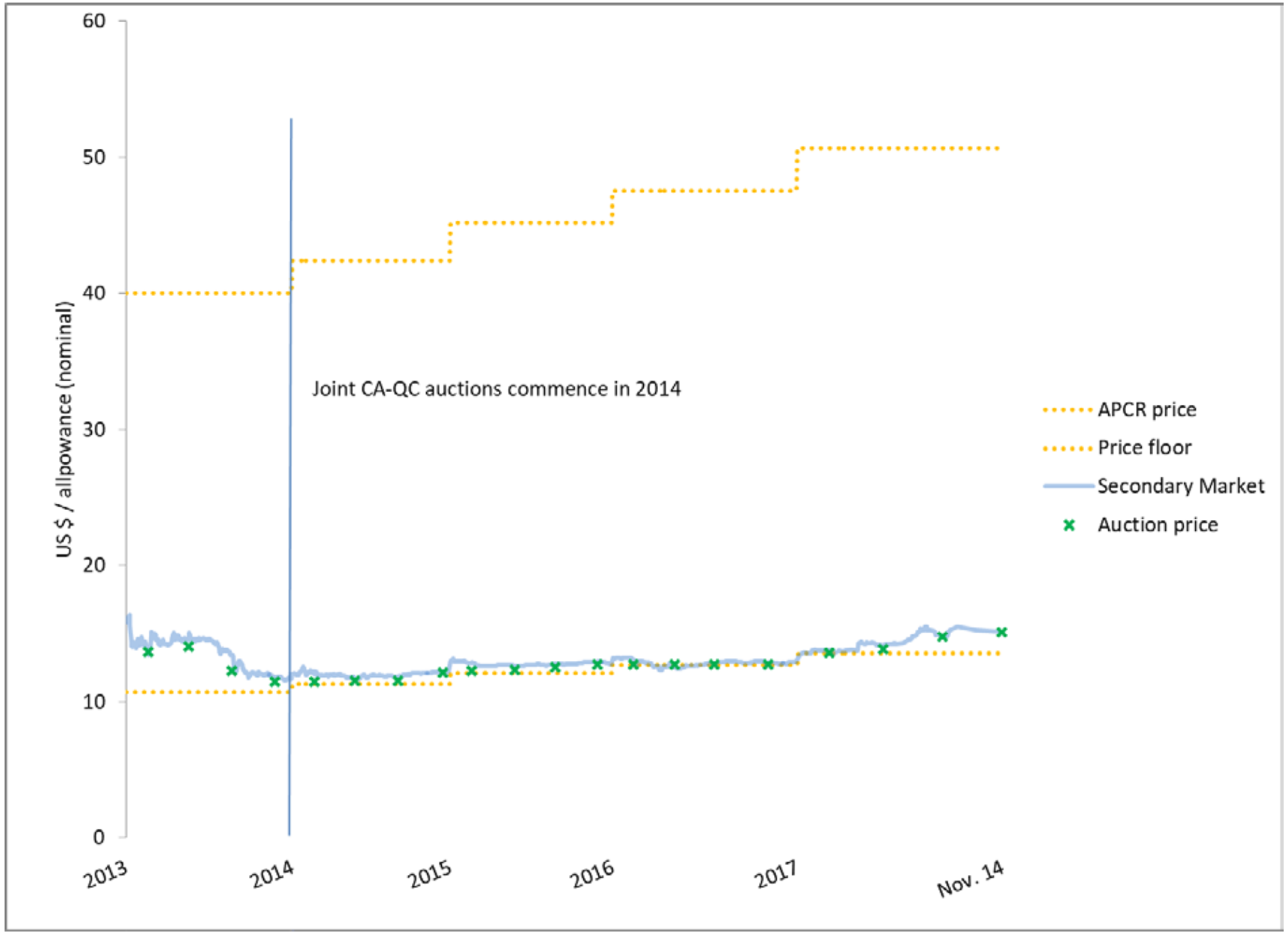


Figure 2. Auction and secondary market prices for current vintage allowances.

(Sources: California Carbon Dashboard, Intercontinental Exchange)[28]

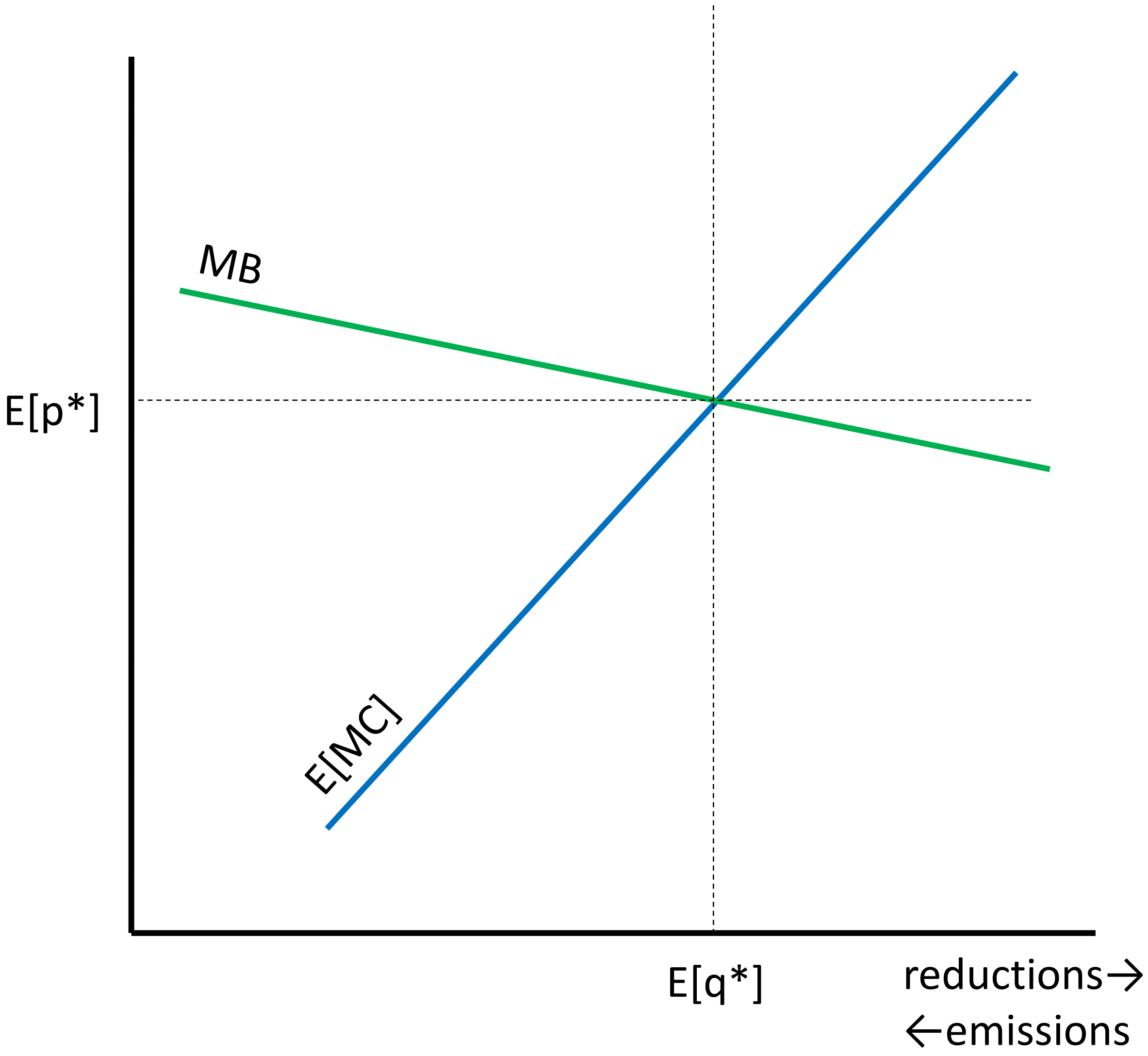
Source: Busch (2017). Oversupply grows in the western climate initiative carbon market. www.energyinnovation.org

#3

Why focus on cap-and-trade with price collar?

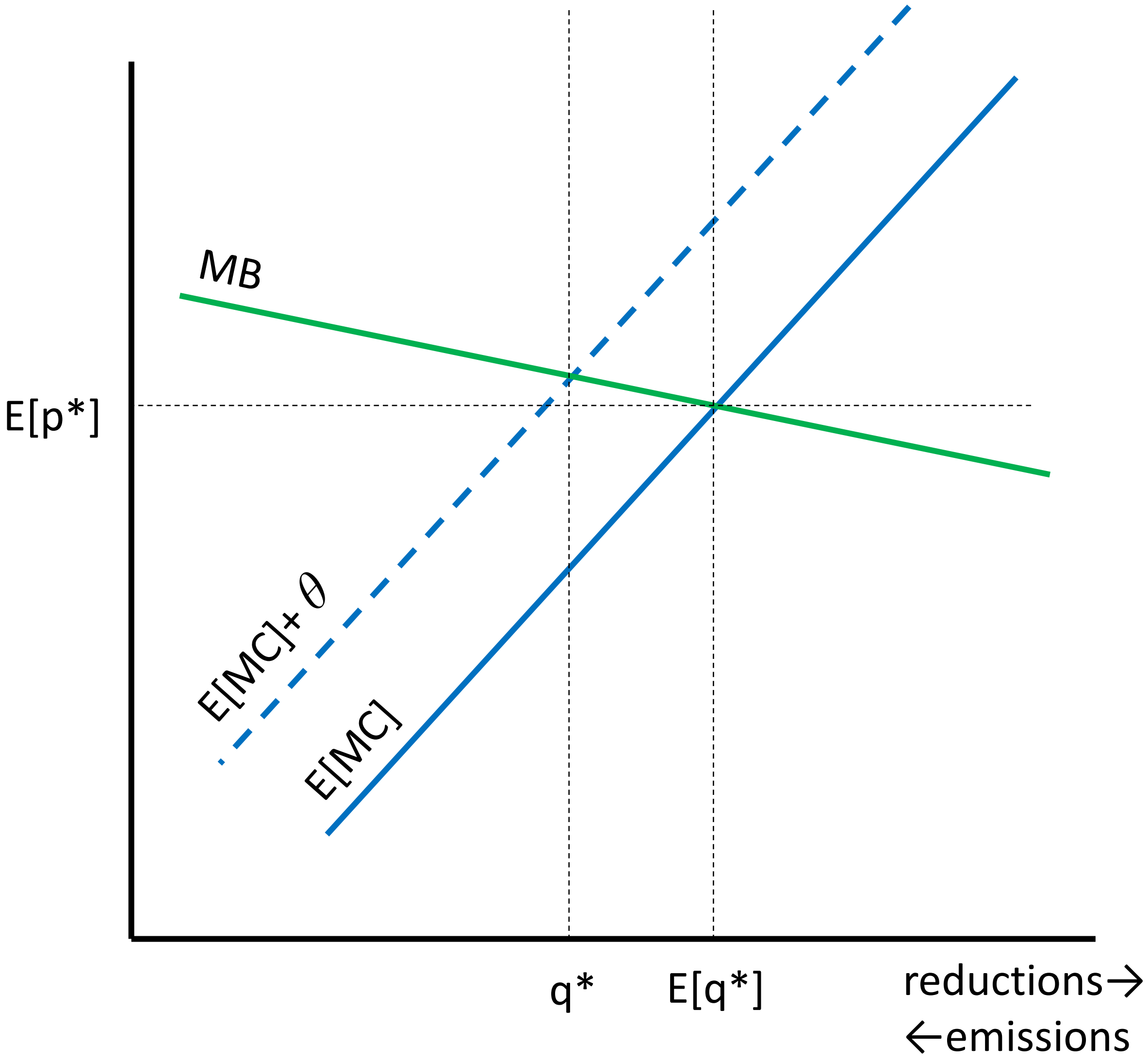
- Welfare. Welfare analysis favors taxes because marginal damages tend to be flat.
  - Why try to make a tax more like an emission limit?

Cap and trade with price collar in theory



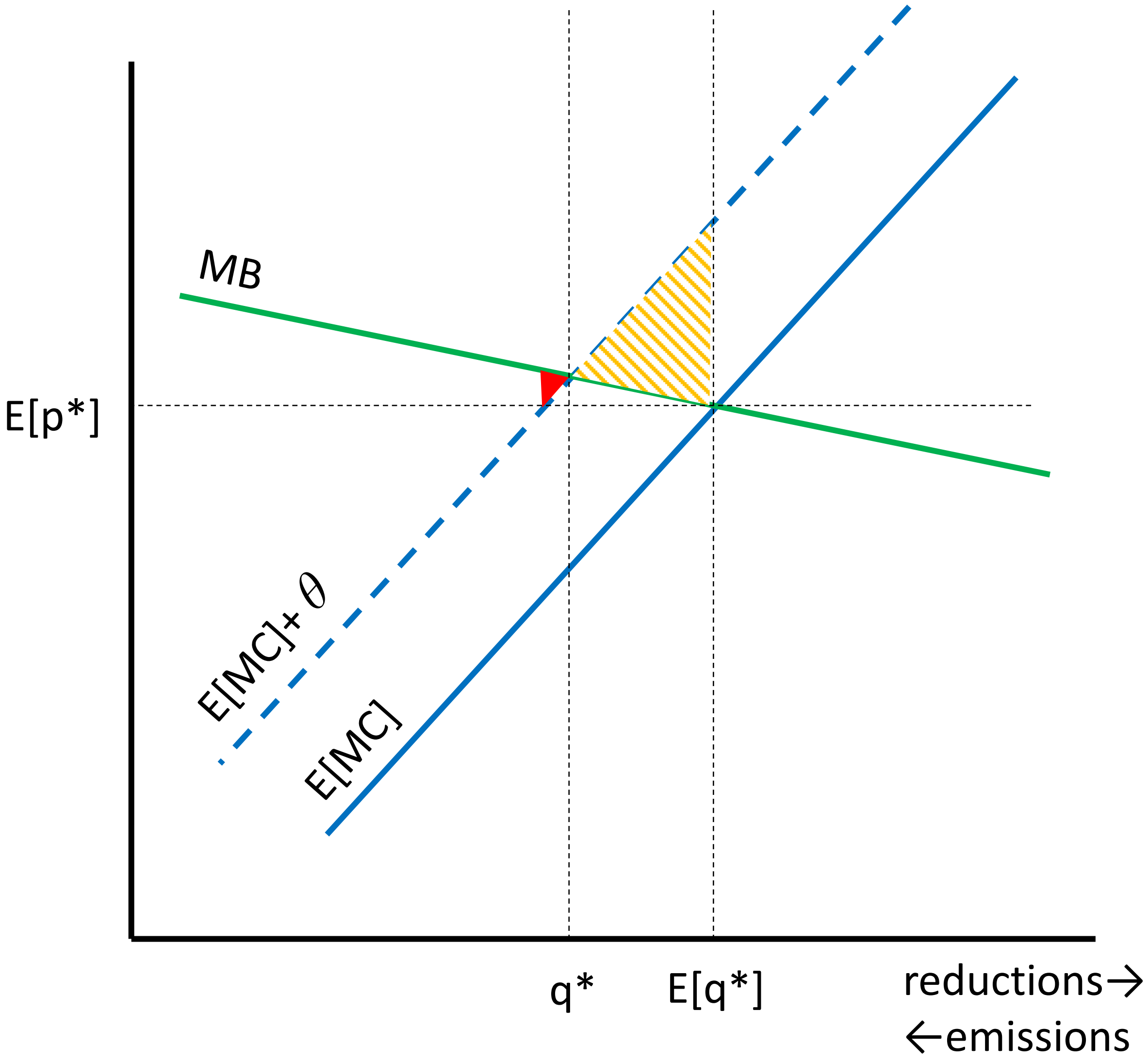
- Prices and quantities yield similar results when costs are known.

Cap and trade with price collar in theory



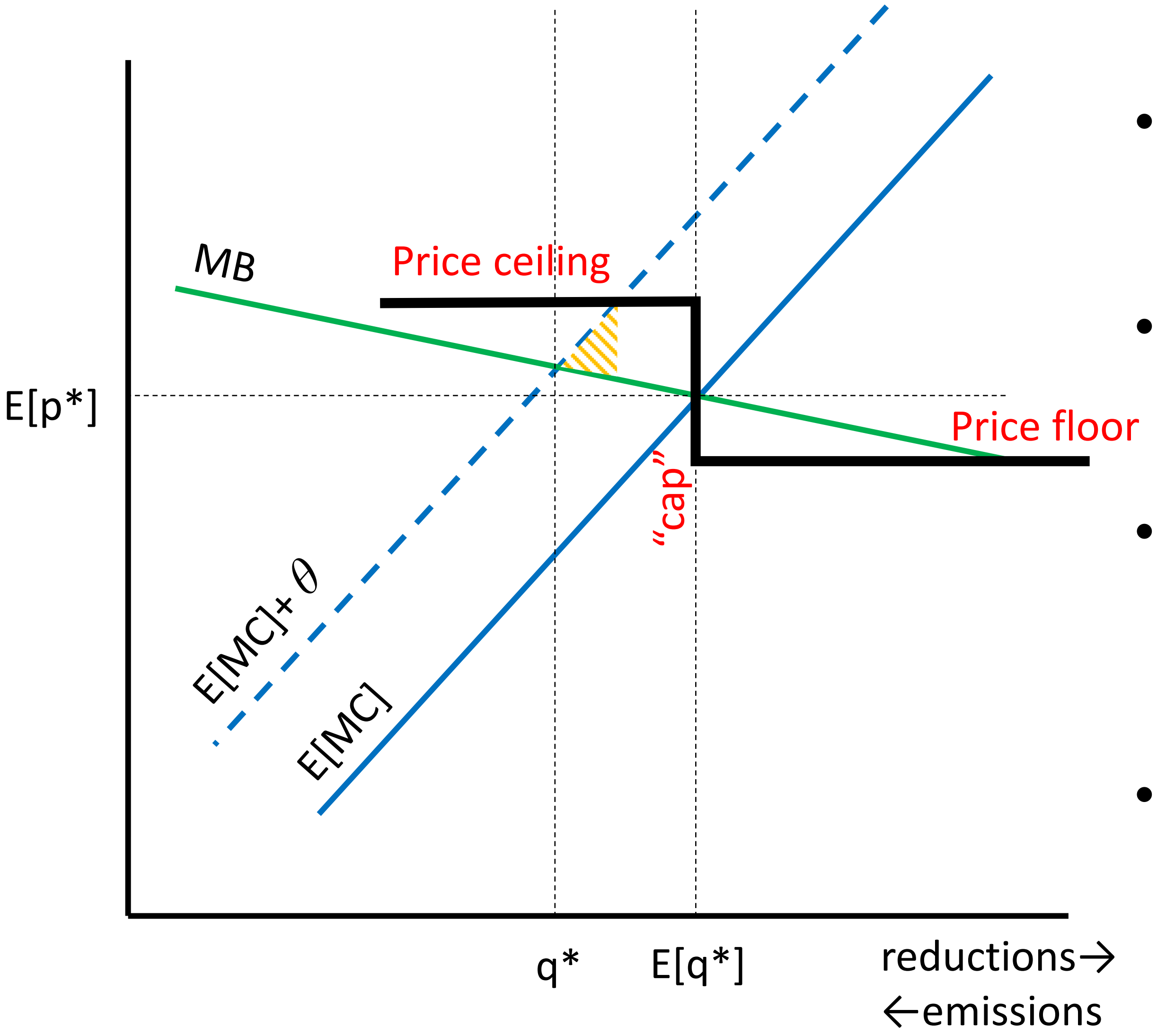
- Prices and quantities yield similar results when costs are known.
- With uncertain cost shocks, outcomes differ.

Cap and trade with price collar in theory



- Prices and quantities yield similar results when costs are known.
- With uncertain cost shocks, outcomes differ.
- When marginal benefits are flat, taxes have a welfare advantage.

Cap and trade with price collar in practice



- Prices and quantities yield similar results when costs are known.
- With uncertain cost shocks, outcomes differ.
- When marginal benefits are flat, taxes have a welfare advantage.
- Price floors and ceilings can achieve the same advantage under quantity regulation.

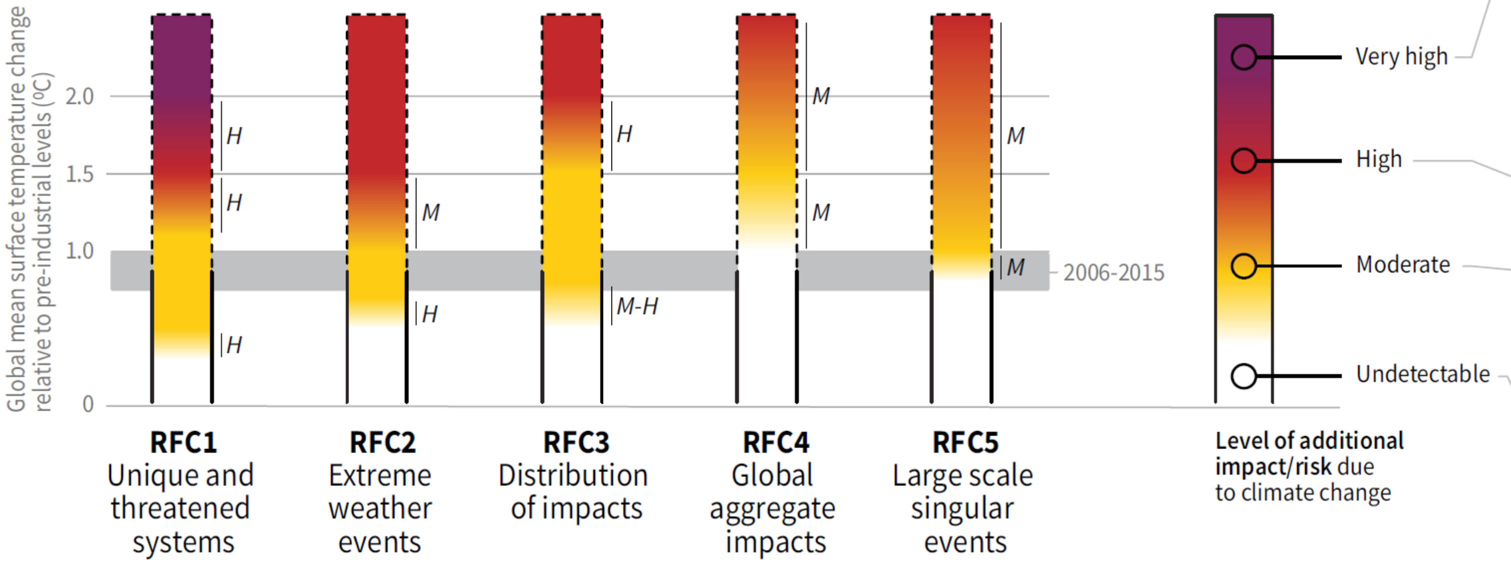
Why do we think marginal damages are flat? (even in terms of cumulative emissions)

- Little evidence of temperature thresholds in empirical literature.
- The probabilistic relationship between cumulative emissions and temperature "smears out" any temperature threshold.
- Uncertainty about other country actions smears out the relationship between US and global emissions.

How the level of global warming affects impacts and/or risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems

Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)



Purple indicates very high risks of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.
Red indicates severe and widespread impacts/risks.
Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
White indicates that no impacts are detectable and attributable to climate change.

Source: IPCC (2018). Global Warming of 1.5°C.

#3

Why focus on cap-and-trade with price collar?

- Welfare. Welfare analysis favors taxes because marginal damages tend to be flat.
  - Why try to make a tax more like an emission limit?
  - If we are trying to make a tax more like an emission limit, what is our objective?
  - How do you combine minimizing costs without some notion of maximizing benefits, if marginal benefits are a vertical line at the target?
  - Even ignoring costs, how bad is it to frequently miss the target a little bit, versus missing it occasionally by a lot?

Table 2 Emissions and costs, Metcalf TAM

	Cumulative costs 2021–2035 ($billion)	Costs per ton of CO_2 emission reductions (2017 dollars)	Cumulative emissions (2020–2035) (billion metric tons)			Probability of achieving emissions target	
	Mean	Mean	Mean	Standard deviation	97.5	Annual	Cumulative
Central case (CC)							
Without TAM	$555.8	$24.5	60.4	4.7	69.1	50.7%	57.7%
With TAM	$599.0	$26.1	60.0	3.4	67.0	68.9%	68.6%
Benchmark paths							
Arbitrary: Metcalf (CC)	$599.0	$26.1	60.0	3.4	67.0	68.9%	68.6%
Arbitrary: straight line	$409.5	$20.3	62.9	4.3	70.5	10.2%	35.4%
Model-based	$641.7	$27.3	59.4	3.5	67.0	81.6%	76.3%

Hafstead and Williams (2020). *Review of Environmental Economics and Policy*, Volume 14, Issue 1, Winter 2020, Pages 95–113

Contribution and Roadmap

- Contributions:
  We develop a welfare objective based on the idea that a quantity target ought to represent a discontinuity in otherwise flat marginal damages from cumulative emissions.
  We use recent policy proposals to calibrate marginal damages
  We then show how we can use this welfare objective to
  1. Pick better parameters for a hybrid tax policy
  2. Motivate better hybrid tax policy designs. Foreshadow: we can beat React…
- Roadmap:
  - Marginal damages as revealed social preferences.
  - Model for simulating emissions and costs.
  - Policy comparisons
    - Simple taxes and ETS.
    - Simple adjustments, but different forms, with parameters based on objective.
  - Key observations and tradeoffs

A welfare objective for a tax paired with an emission target

- Stakeholders are focused on a cumulative emission target, say $\bar{E}$, are willing to vary the tax up to a point to achieve it.
- Suggests a marginal benefit/damage function:

$$MD(E_T) = a + (b - a) \cdot 1(E_T \geq \bar{E})$$

where E_T is cumulative emissions in a final period T, $MD(E_T)$ represents marginal damages, and $b > a$.

- Welfare measured across many states of nature s is then given by

$$-S^{-1} \sum_{s=1}^{S} \left(aE_T^s + (b-a)(E_T^s - \bar{E}) 1(E_T^s \geq \bar{E}) \right) - \sum_{t=1}^{T} e^{-\delta t} C_t^s(e_t^s)$$

climate damages in final period T *mitigation costs*

Calibrating a damage function

SEPTEMBER 2019 | U.S. POLICY

CARBON PRICING PROPOSALS IN THE 116TH CONGRESS

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

Jason Ye, Center for Climate and Energy Solutions

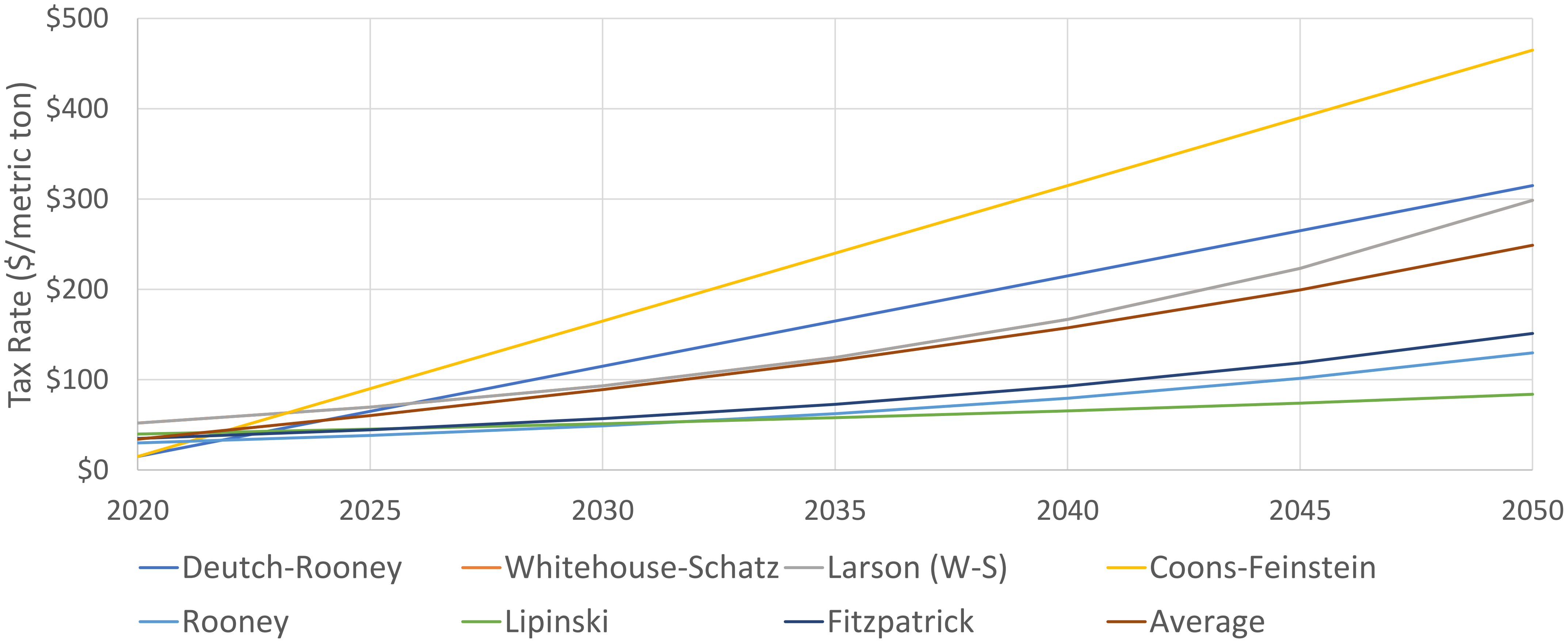
There are various market-based approaches to pricing carbon (e.g. carbon tax, cap and trade, and a clean energy standard). All of these can reduce emissions cost-effectively while driving clean energy innovation. This factsheet compares eight carbon tax and cap-and-dividend proposals introduced in the 116th Congress (2019–2020).

Calibrating a damage function

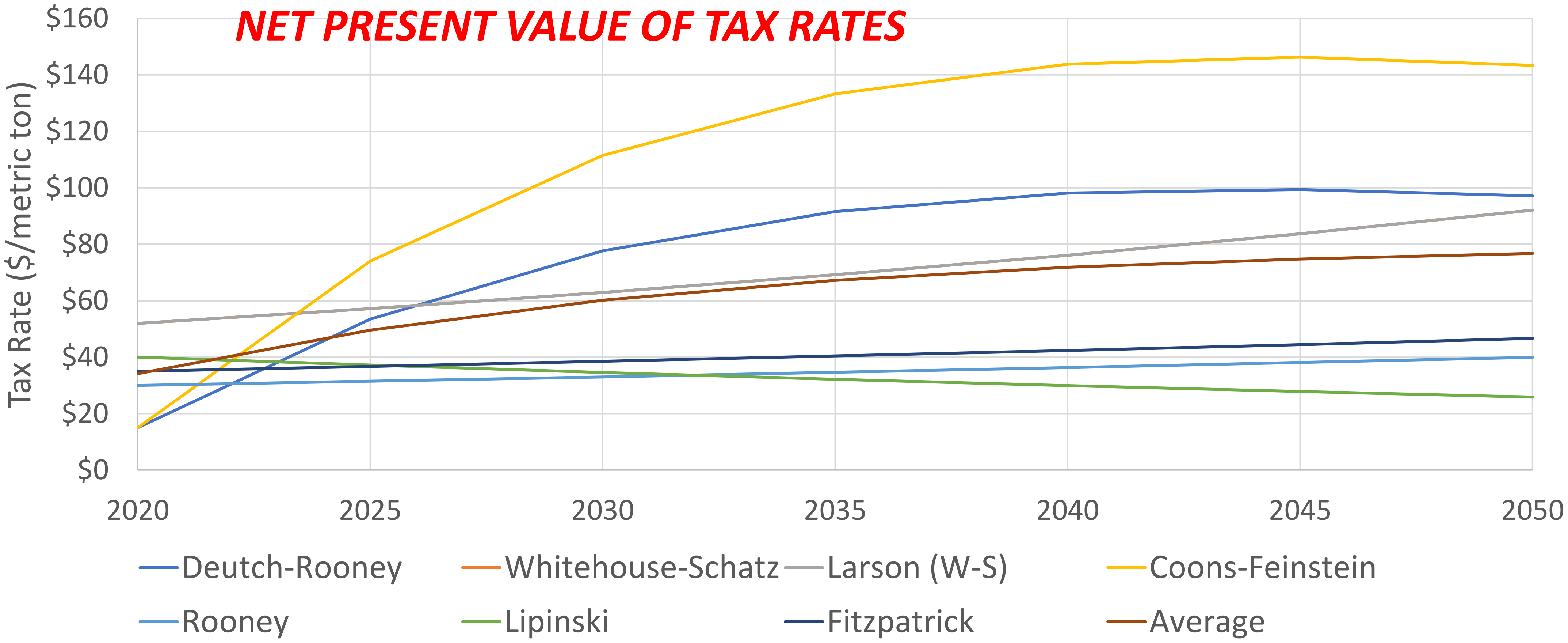
Policy Proposal	Carbon Price and Escalation Rate
Deutch-Rooney	Starts at $15/ton. Increases $10/year, or $15 if target not met in previous year.
Whitehouse-Schatz	Starts at $52/ton. Increases annually 6% above CPI. *Increases by only CPI when emissions at least 80% below 2005 levels.*
Coons-Feinstein	Starts at $15/ton. Increases $15/year, or $30/year if target not met in previous year.
Rooney (and Lipinksi)	Starts at $30/ton. Increases annually 5% above CPI. Increases by additional $3/ton biennially if cum. emissions > target.
Lipinski (and Rooney)	Starts at $40/ton. Increases annually 2.5% above CPI. *Escalation phased out once emissions 80% below 2005 levels.*
Larson	Starts at $52/ton. Increases annually 6% above CPI.
Fitzpatrick-Carbajal	Starts at $35/ton. Increases annually at 5% above CPI, and additional $4/ton biennially if cum. emissions > target.

Note: Van Hollen – Beyer is only a cap.

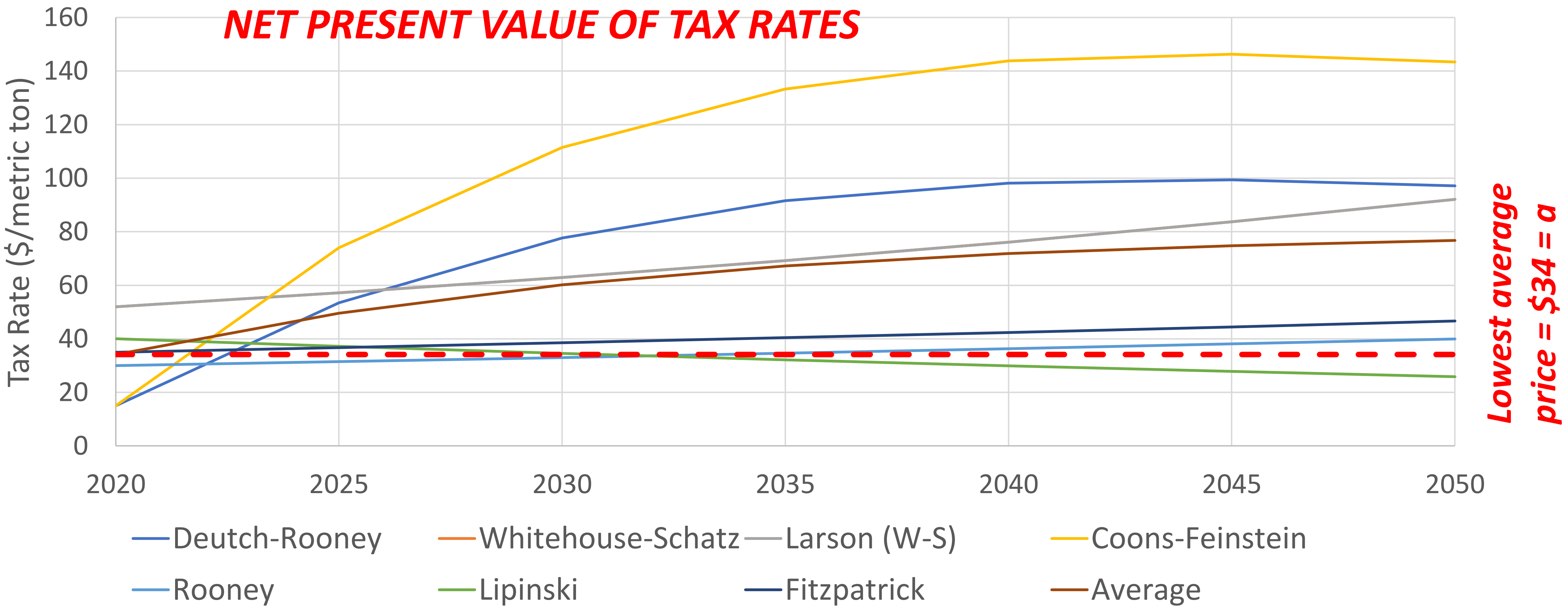
Calibrating a damage function
Tax rates for the seven proposals with a tax rate



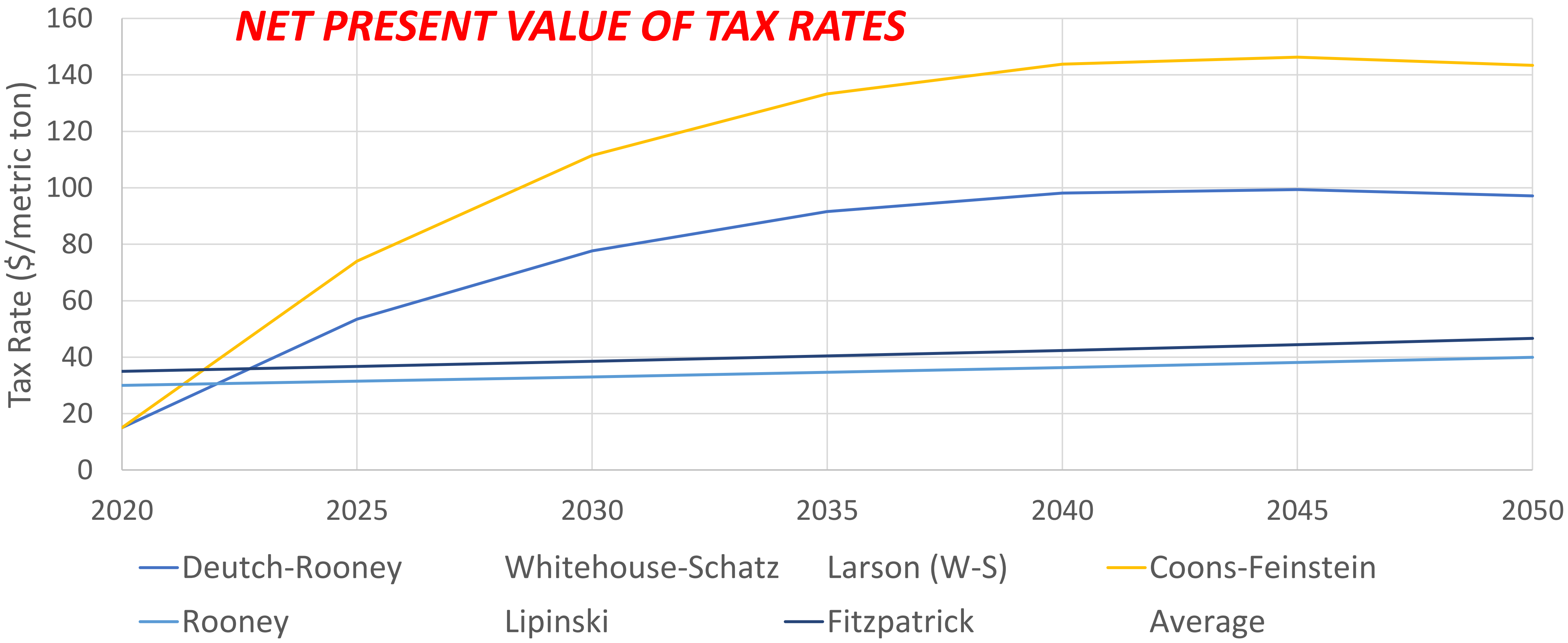
Calibrating a damage function
Tax rates for the seven proposals with a tax rate



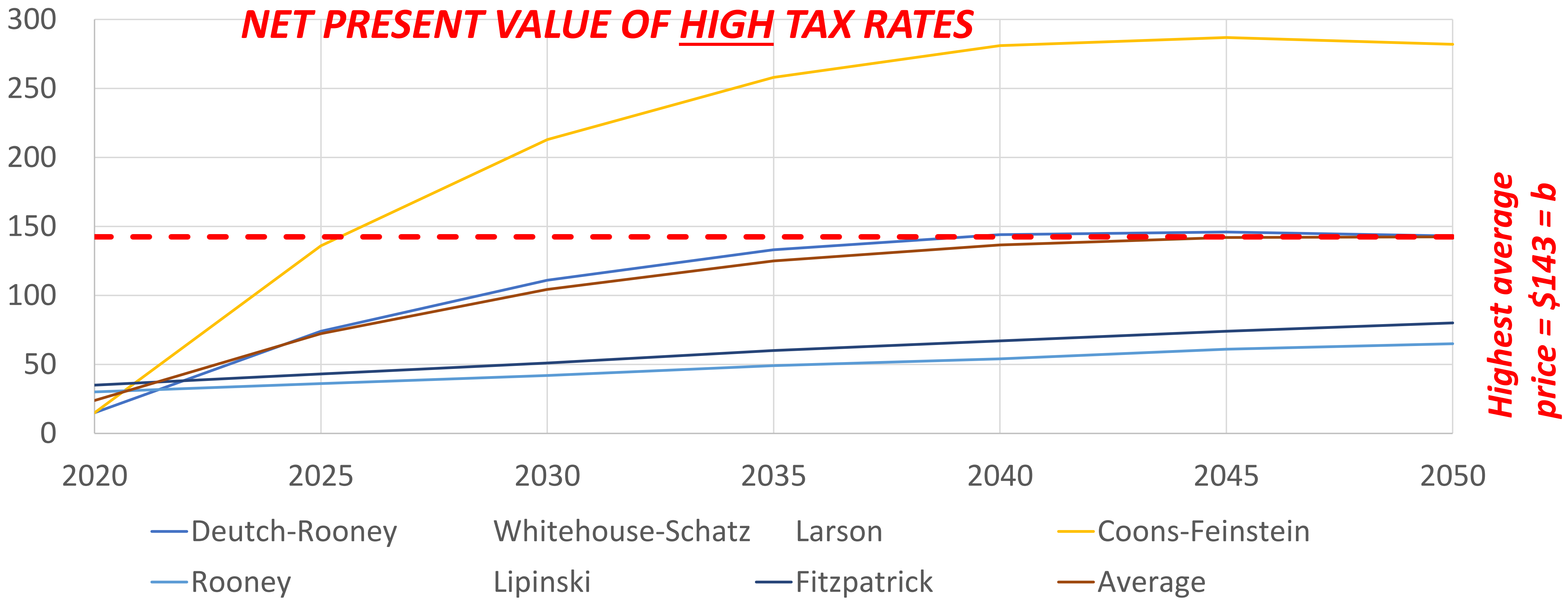
Calibrating a damage function
Tax rates for the seven proposals with a tax rate



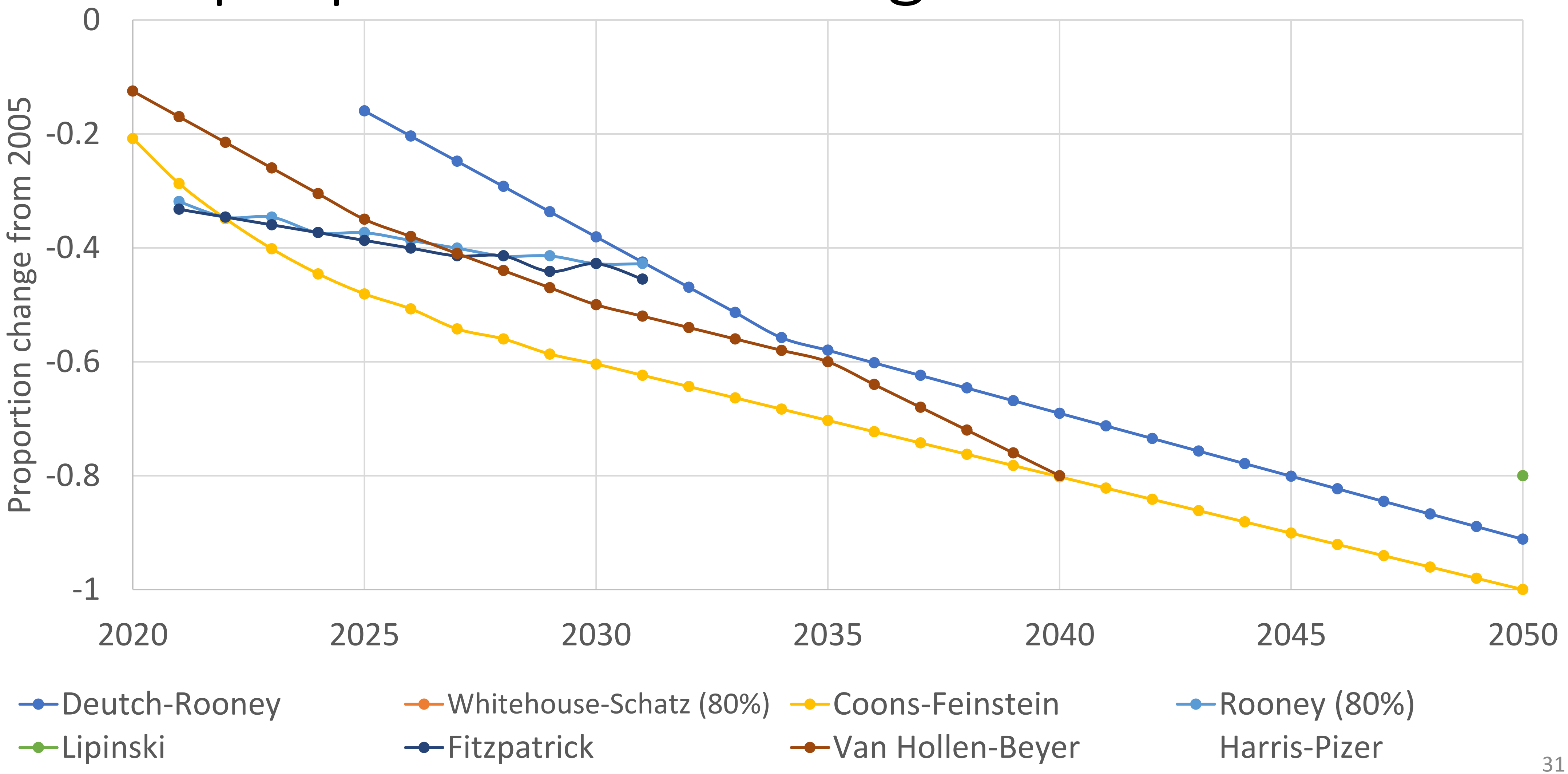
Calibrating a damage function
Four proposals with a "high" tax rate



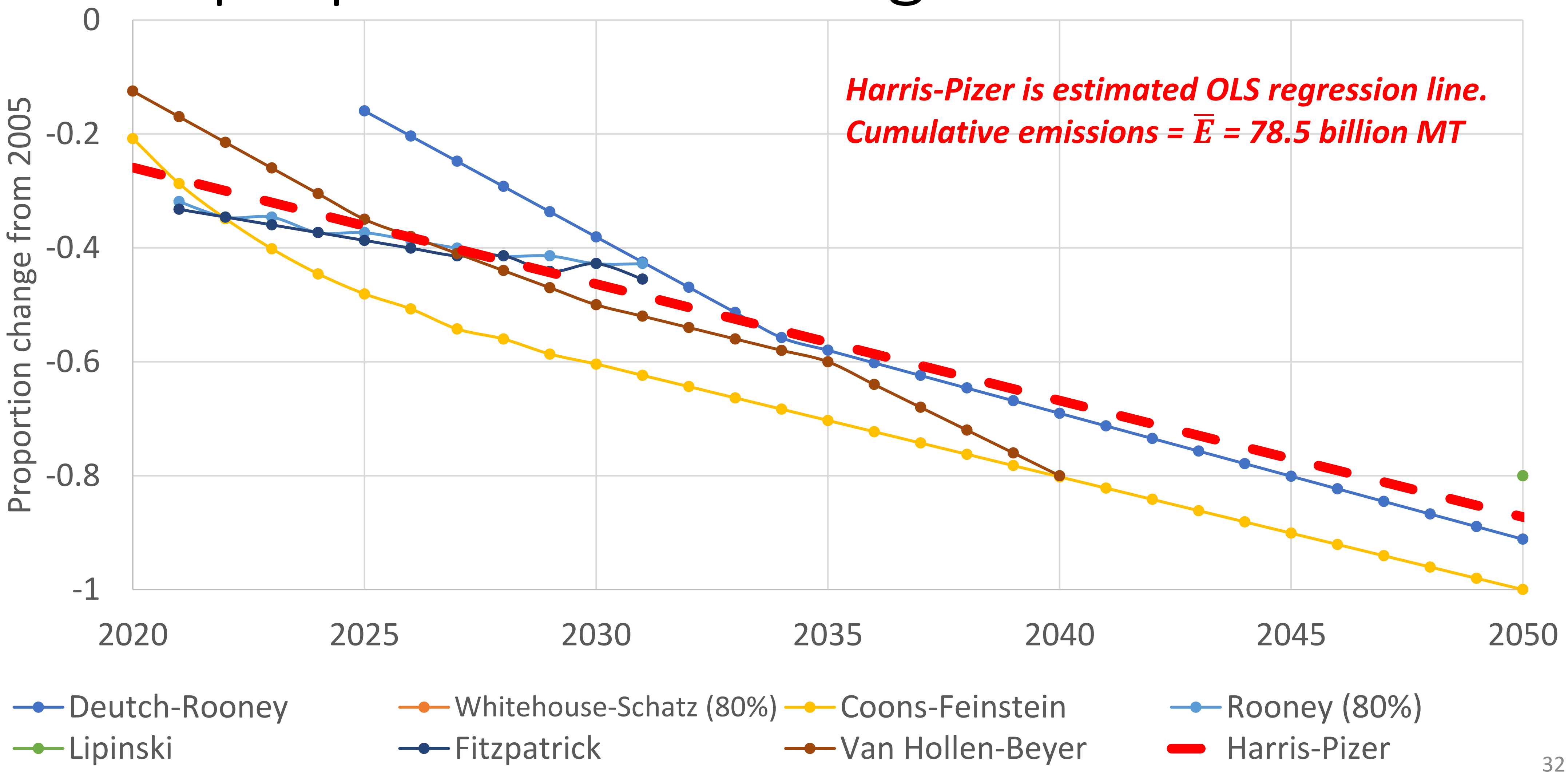
Calibrating a damage function
Four proposals with a "high" tax rate



Calibrating a damage function
Seven proposals with a target



Calibrating a damage function
Seven proposals with a target



Calibrating a cost function
Uncertainty about future emissions

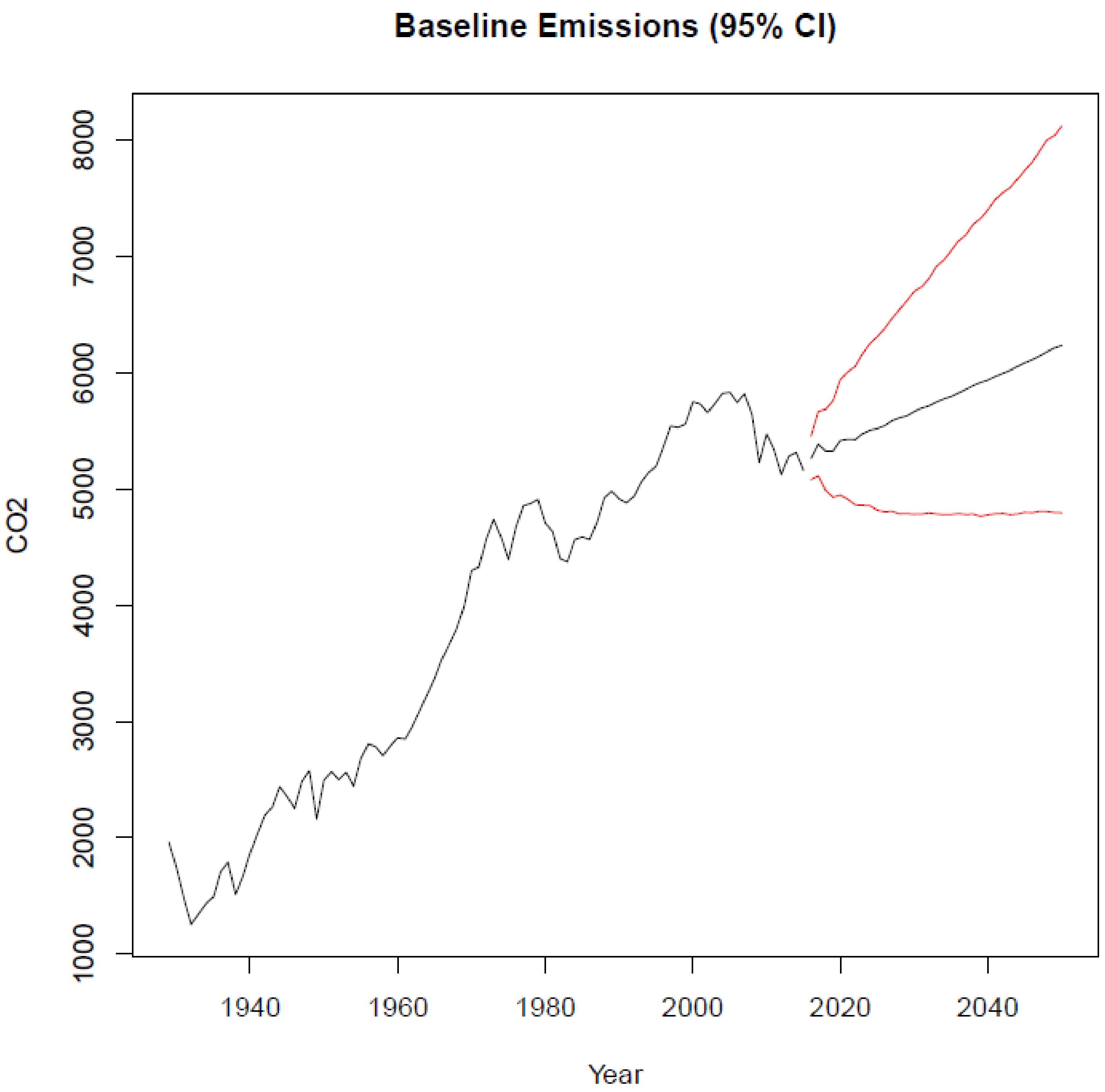
- Real GDP

$$\Delta \log(Y_t) = \phi \Delta \log(Y_{t-1}) + \mu_g(1-\phi) + \varepsilon_t$$

- Emissions intensity (E/Y)

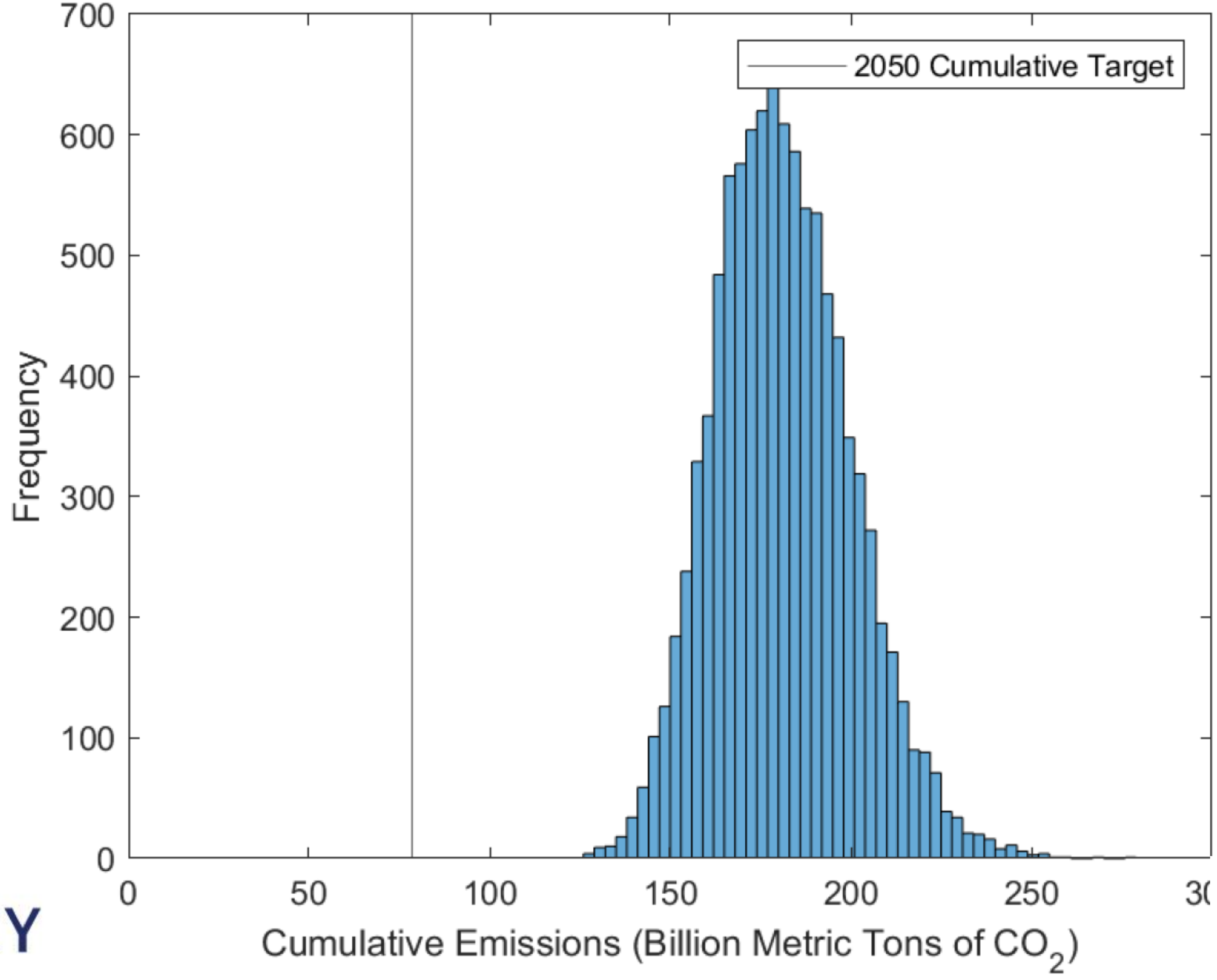
$$\Delta \log\left(\frac{e_t}{Y_t}\right) = \alpha_1 \Delta \log\left(\frac{e_{t-1}}{Y_{t-1}}\right) + \alpha_2 \Delta \log\left(\frac{e_{t-2}}{Y_{t-2}}\right)$$
$$+\mu_r\big(1-(\alpha_1+\alpha_2)\big) + \eta_t$$

- Data
  - Use 1985-2015
  - GDP (Y): Chained 2009$
  - CO_2 (E): U.S. carbon dioxide emissions



Baseline Emissions (95% CI)
CO2
8000
7000
6000
5000
4000
3000
2000
1000
1940
1960
1980
2000
2020
2040
Year

Calibrating a cost function
Uncertainty about future emissions

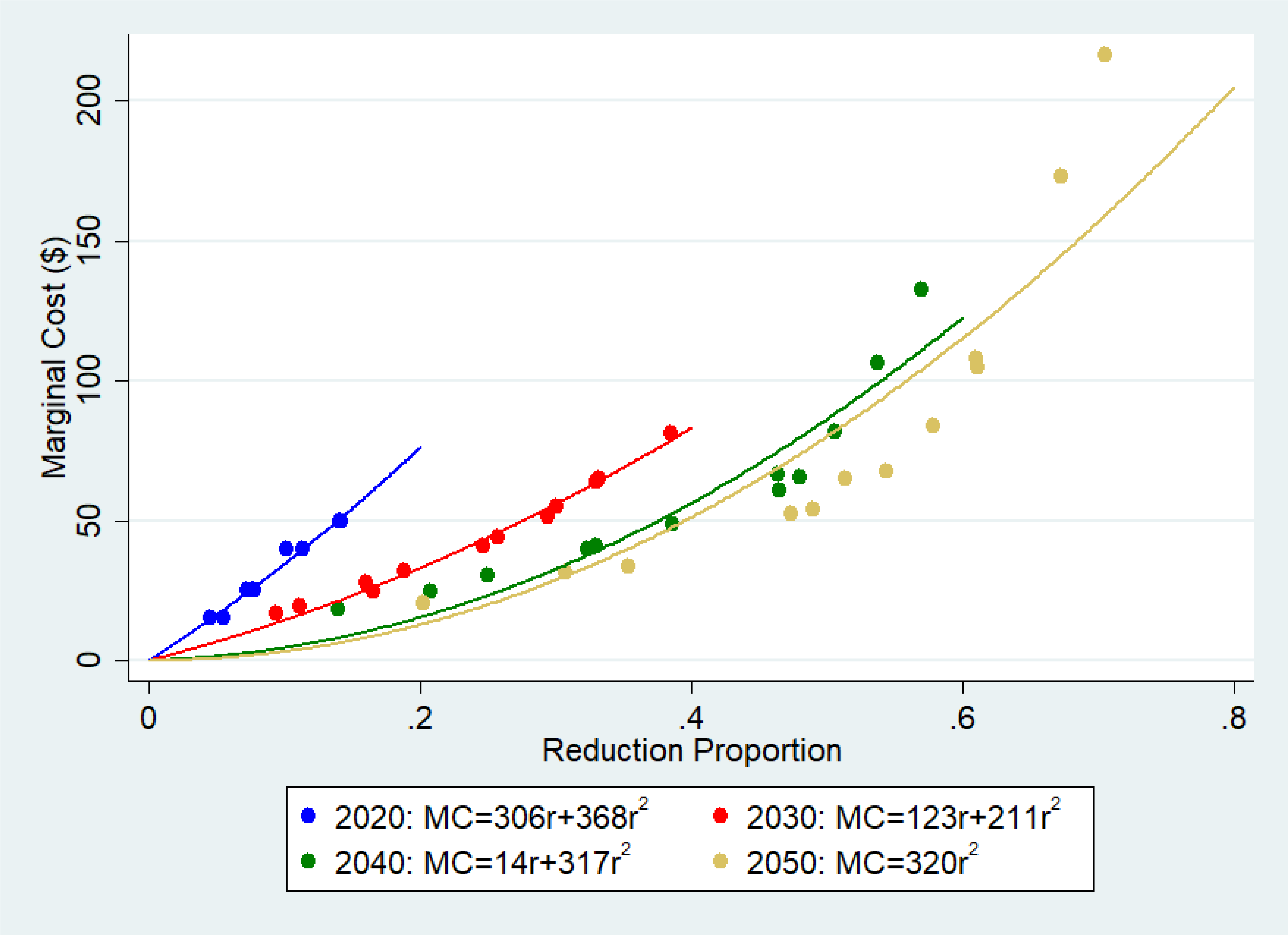


Calibrating a cost function
Estimating mitigation costs

- Martin Ross DIEM-CGE model
- Emission reduction:

$$MC_t(r_t) = \beta_{1,t} r_t + \beta_{2,t} r_t^2$$

- For simulations:
  - Realized emissions:
    $$(1 - r_t(tax))\widehat{e_t}$$
    where $\hat{e}$ is predicted baseline emissions
  - Costs: area under marginal cost curve
    NPV each year (discounted at 4%)
    Summed (and sometimes annualized)



Marginal Cost ($)
0
50
100
150
200
0
.2
.4
.6
.8
Reduction Proportion
2020: MC=306r+368r2
2030: MC=123r+211r2
2040: MC=14r+317r2
2050: MC=320r2

Summarizing:
Climate damages and mitigation costs model:

- Climate damages
  - \$34 per ton up to 78 billion tons cumulative emissions, then \$143 per ton.

$$-S^{-1}\sum_{s=1}^{S}\left(\$34E_T^s + \$109(E_T^s - 78)1(E_T^s \geq 78)\right) - \sum_{t=1}^{T} e^{-\delta t} C_t^s(e_t^s)$$

  - Baseline emissions are about 180 billion cumulative tons 2020-2050 (6 billion / year).
  - Baseline damages ~\$1 trillion / year.
- Mitigation costs
  - 30% reductions start at ~\$125/ton, \$125B/year in 2020
  - 30% decline to ~\$25/ton in 2050, \$25B/year in 2050

Different possible policies

- "ETS." Each period, use a forecasting model to set the price to be the best estimate of the cost-minimizing path to hit the target. *Approximates what a cap-and-trade policy would do.* (a) regular ETS; (b) with $34<prices<$134.
- Standard tax. (c) expected emissions match target; (d) maximize objective.
- O-Level. Two price paths, different starting prices, both rising at 4%. Price each period is chosen from one of the two paths, depending on whether cumulative emissions exceed a threshold.
- O-Growth. Two price paths, one starting price, different growth rates. Price each period is chosen from one of the two paths, depending on whether cumulative emissions exceed a threshold.
- O-React. One starting price. Carbon price rises each period by 4% or a "penalty" rate, depending on whether cumulative emissions exceed a threshold.

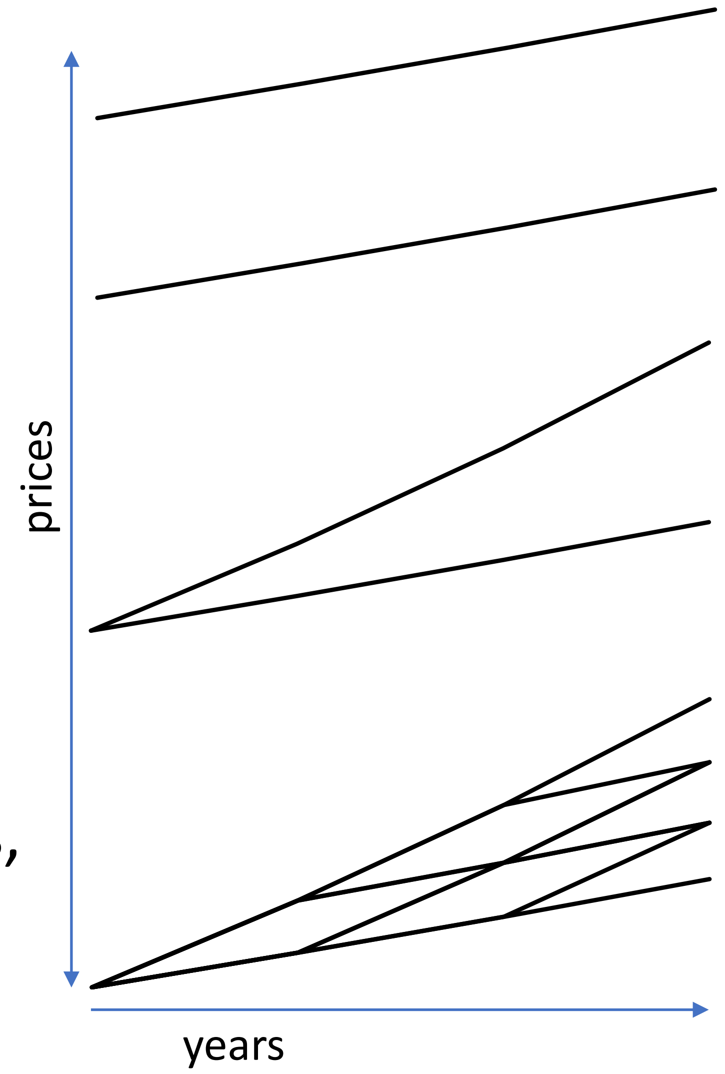
All parameters and cumulative emission thresholds for "O-policies" chosen to maximize welfare

Different possible policies

- O-LEVEL.
  parameters: thresholds, high/low price

- O-RATE.
  parameters: thresholds, starting price, high/low growth

- O-REACT.
  parameters: thresholds, high/low growth

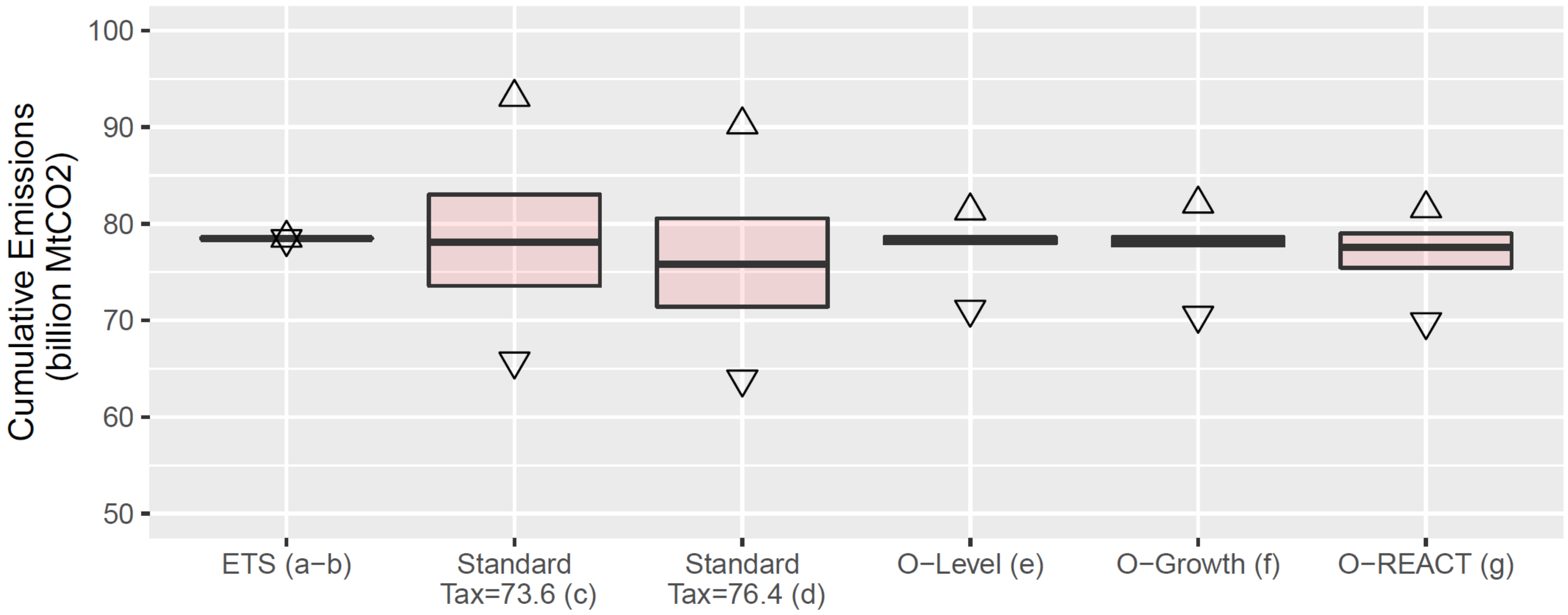


O-Level, and O-Growth, O-React allow the various policy parameters to be endogenously determined in 2020 to maximize welfare.

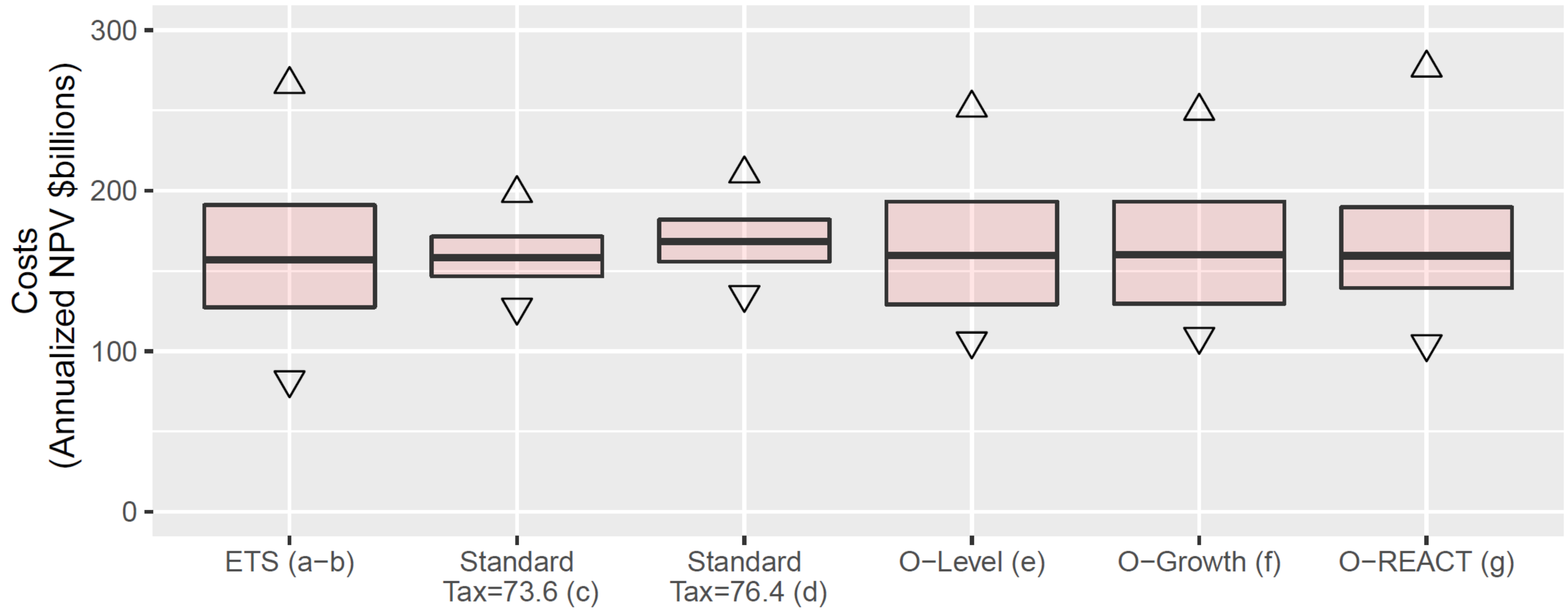
Results

	Mitigation costs ($B/yr)	Climate damages ($B/yr)	Net benefits relative to no policy ($B/yr)	Net benefits relative to ETS (%)	Net benefits relative to tax, ÷ ETS relative to tax (%)	Expected cumulative emissions (billion MT)	Expected marginal damages ($/ton)
No policy	0.00	985.40	0.00	-100	NA	181.3	142.50
(a-b) ETS & price collar	161.72	152.21	671.47	0.0	100	78.5	85.84
(c) Tax to hit target	159.71	169.46	656.24	-2.3	-0.1	78.5	85.98
(d) Tax to min objective	169.57	158.46	657.37	-2.1	0.0	76.2	71.99
(e) O-Level	164.80	152.70	667.90	-0.5	74.7	77.9	72.79
(f) O-Growth	165.24	152.71	667.44	-0.6	71.4	77.8	71.01
(g) O-REACT	168.46	152.06	664.88	-1.0	53.3	77.0	70.38

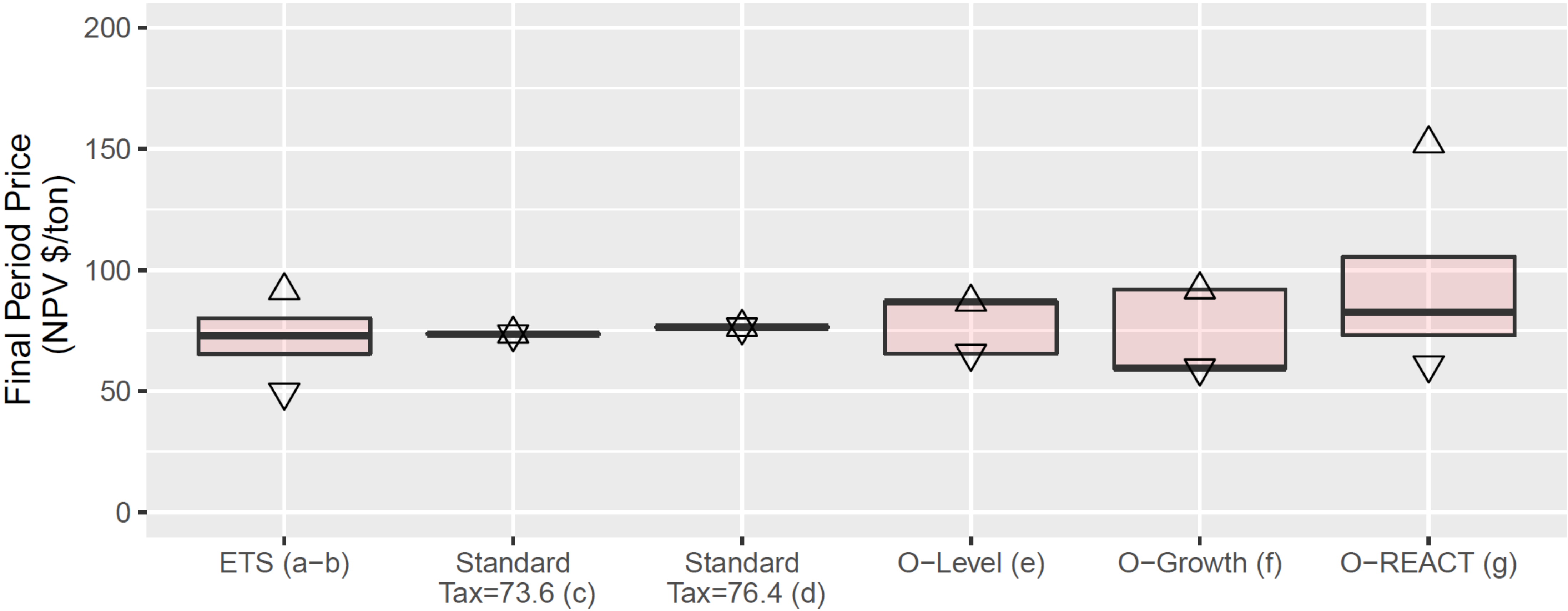
Results: Cumulative emissions



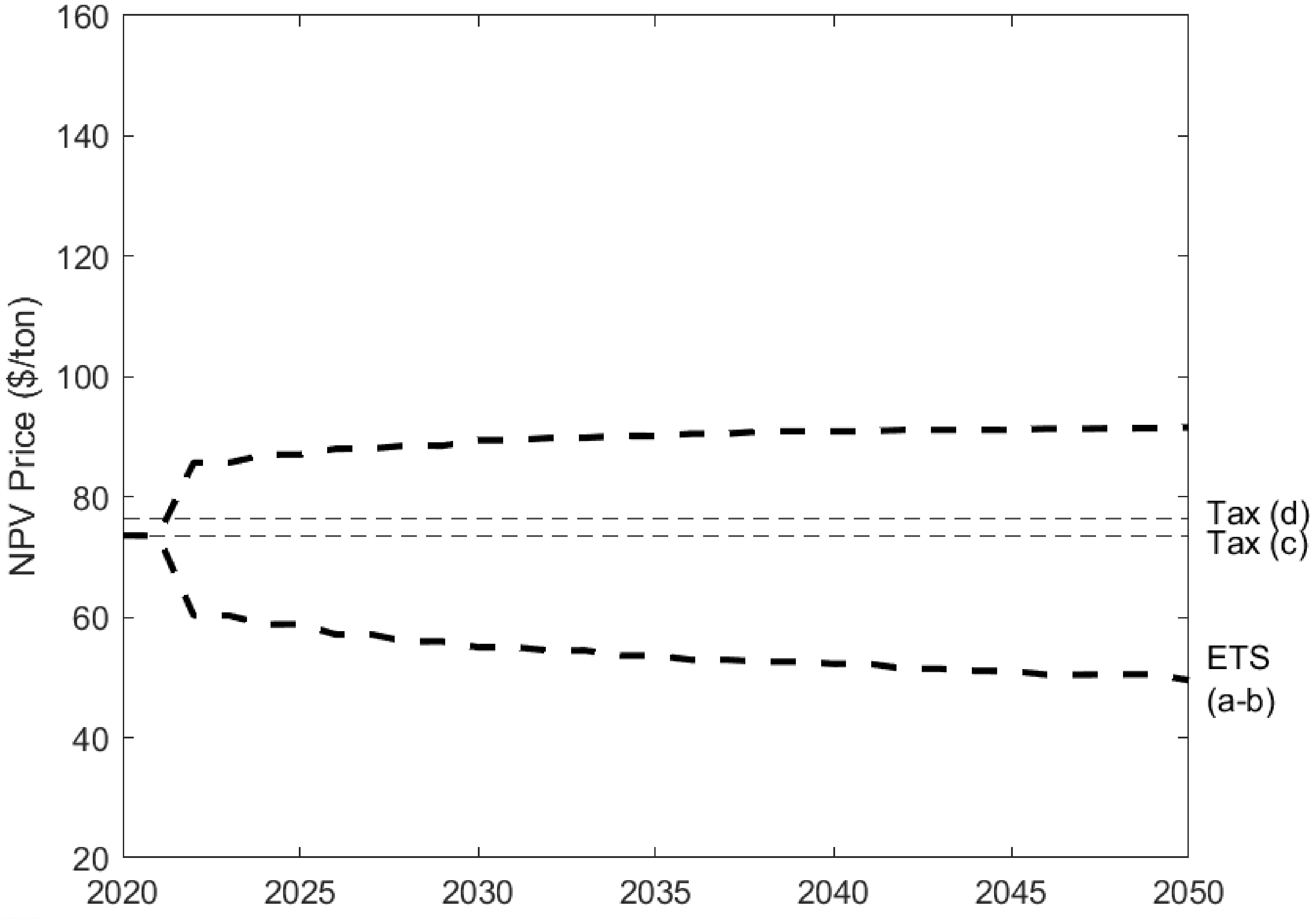
Results: NPV Costs (annualized)



Results: Final Price (discounted to 2020)

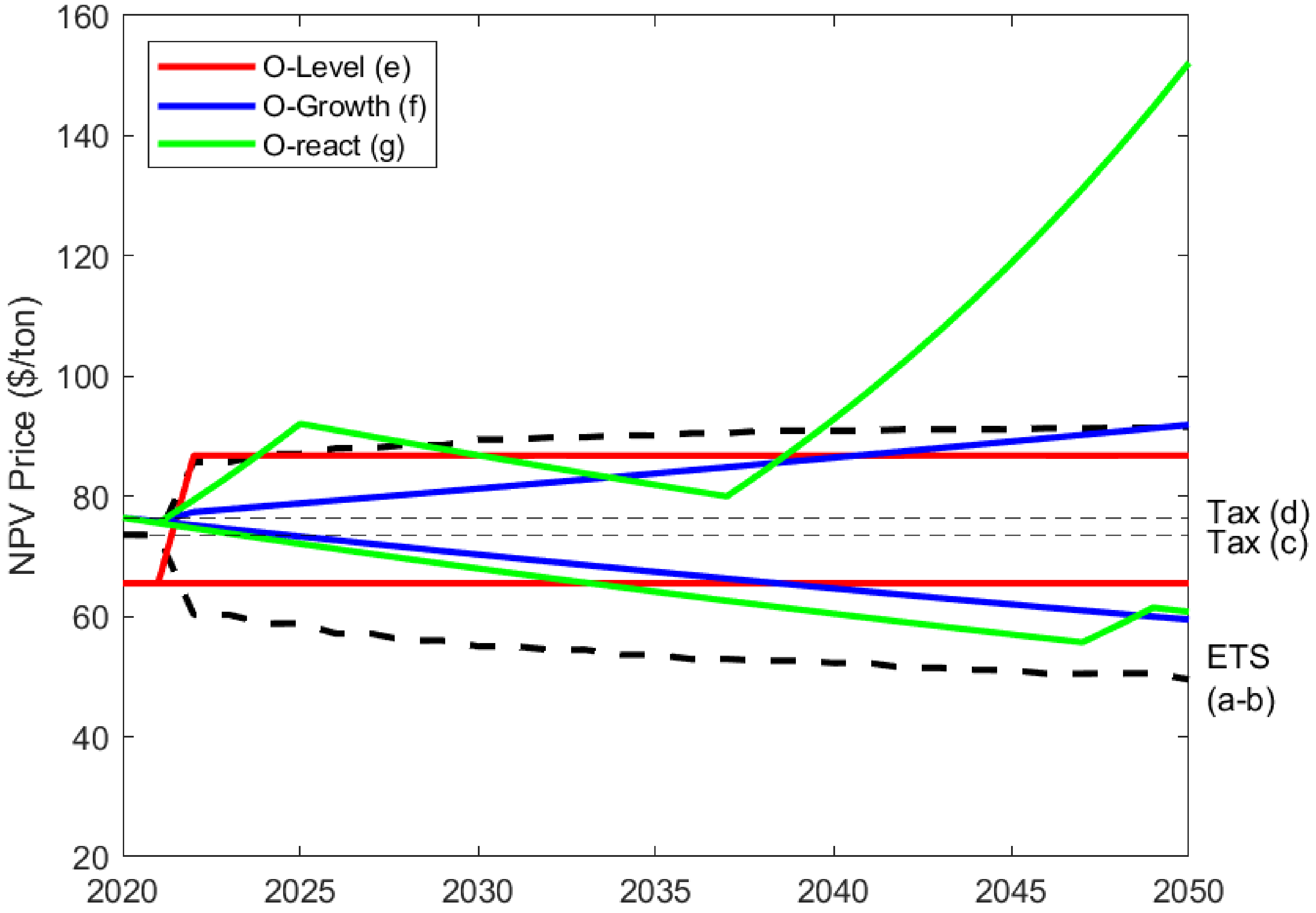


Price paths



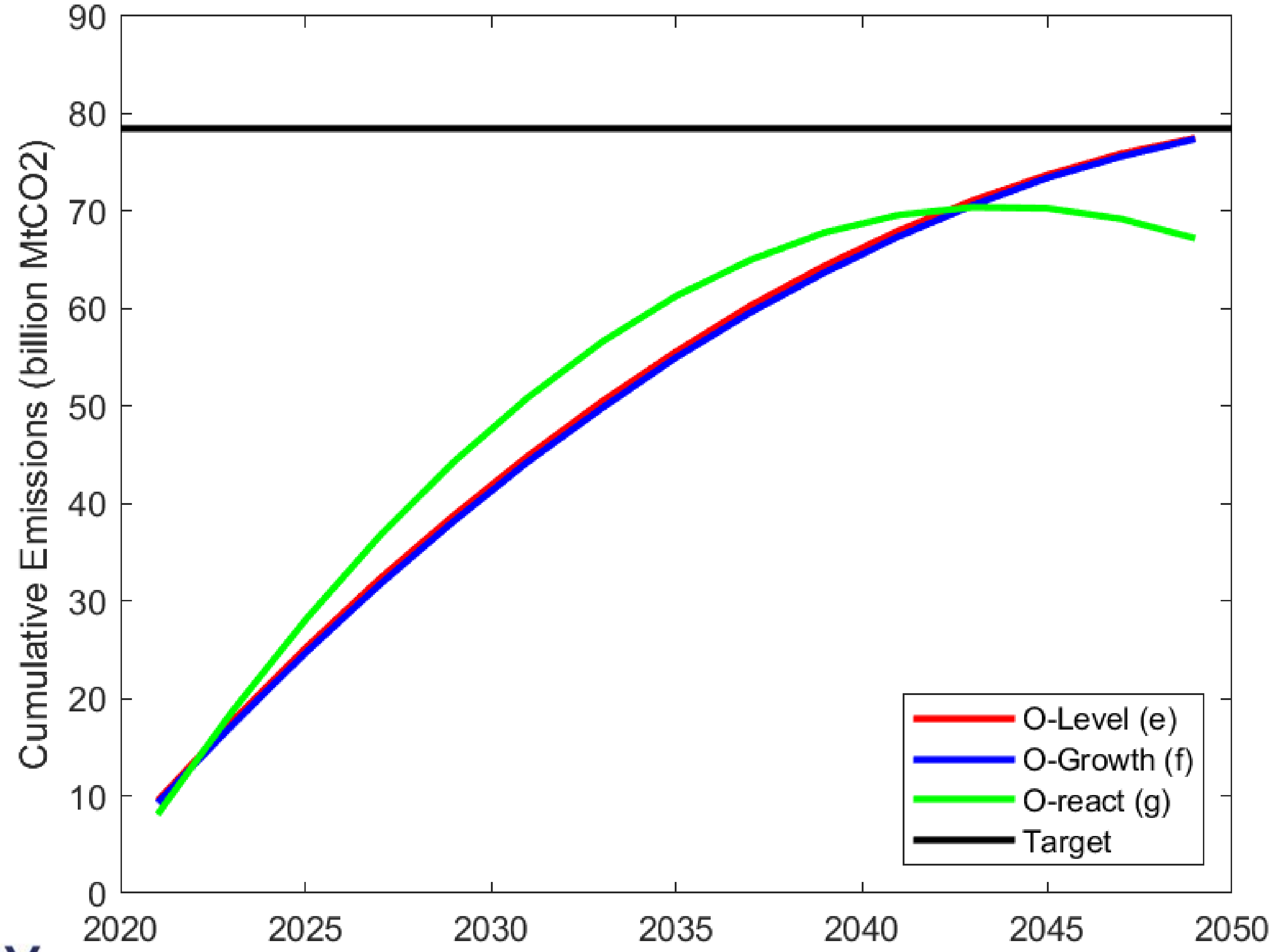
NPV Price ($/ton)
160
140
120
100
80
60
40
20
2020
2025
2030
2035
2040
2045
2050
Tax (d)
Tax (c)
ETS
(a-b)

Price paths



160
140
120
100
80
60
40
20
NPV Price ($/ton)
2020
2025
2030
2035
2040
2045
2050
O-Level (e)
O-Growth (f)
O-react (g)
Tax (d)
Tax (c)
ETS
(a-b)

Cumulative emission thresholds



Conclusions

1. Carbon taxes that adjust based on an emission target require rethinking our welfare measure, perhaps based on a revealed preference climate damage function.
2. With a welfare function in hand, we can examine optimized policies as well as compare variations in the policy design.
3. *Simulations:* The welfare differences among all the policies are relatively small compared to the overall welfare gain. This is because the reductions are quite substantial compared to the uncertainty.
4. *Simulations:* All the optimized tax policies that adjust to try hit the target do well compared to a simple tax—achieving 50-75% of the welfare difference between the simple tax and the optimal ETS.
5. *Simulations:* A policy that allows larger price adjustments in the future performs better. In the future, there is more confidence about whether you are above or below the target.