Mechanisms to Reduce Emissions Uncertainty under a Carbon Tax

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April 17, 2018
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Hybrid Policy Solutions

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- Substantial literature on cap-and-trade hybrid policies

- Upward sloping allowance supply curves: Burtraw et al. (2018)
- Limited literature on carbon tax hybrid policies
  - Metcalf (2009): The REACT proposal and illustrative modeling
  - Hafstead et al. (2017) consider
  - Murray et al. (2017) consider
    - Regulatory Backstop
    - Dedicated Use of Unanticipated Revenue
  - Aldy (2017) considers
    - “Structured Discretion”
  - Harris and Pizer (2018)
    - Simulation modeling with “Price Updating in Expectation”

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Key Research Questions

- How uncertain are emissions under a carbon tax?
  - What are the drivers of emissions uncertainty?
Key Research Questions

- How uncertain are emissions under a carbon tax?
  - What are the drivers of emissions uncertainty?
- What are the costs of providing emissions certainty under a carbon tax?
  - How do the costs vary by mechanism design?
  - What are the trade-offs across different designs?
How uncertain are emissions under a carbon tax?
- The confidence interval for cumulative emissions is quite large
  - \(+/- 24\) percent of expected cumulative emissions
- Uncertainty in the price elasticity drives emissions uncertainty

What are the additional expected costs of providing emissions certainty under a carbon tax?
- Depends on how we define certainty
- Depends on key design choices
  - 5 - 80\% of primary cost
Outline

- Intro
- Emissions Certainty Mechanisms Examples
- Reduced-Form Model of Emissions with Uncertainty
- Quantifying Emissions Uncertainty
- Defining Emissions Certainty
- Comparing Tax Adjustment Mechanisms
Intro

Emissions Certainty Mechanisms Examples

Reduced-Form Model of Emissions with Uncertainty

Quantifying Emissions Uncertainty

Defining Emissions Certainty

Comparing Tax Adjustment Mechanisms
From Metcalf (2009),

“REACT takes the following approach:

- An initial tax and standard growth rate for the tax is set for the first year of a control period.

- Benchmark targets for cumulative emissions are set for the control period. The law could require that the targets be met at annual, five-year, ten-year or some other time interval.

- If cumulative emissions exceed the target in the given years, the growth rate of the tax would rise from its standard growth rate to a higher catch-up rate until cumulative emissions fall below the target again.”
In 2012, the CO$_2$ Ordinance specified “The levy shall be increased as follows:

- From 1 January 2014: at 60 francs per tonne CO$_2$ if the CO$_2$ emissions from thermal fuels in 2012 exceed 79 percent of 1990 emissions;
- From 1 January 2016: at 72 francs per tonne CO$_2$ if the CO$_2$ emissions from thermal fuels in 2014 exceed 76 percent of 1990 emissions, at 84 francs per tonne CO$_2$ if the CO$_2$ emissions from thermal fuels in 2014 exceed 78 percent of 1990 emissions;
- From 1 January 2018: at 96 francs per tonne CO$_2$ if the CO$_2$ emissions from thermal fuels in 2016 exceed 73 percent of 1990 emissions, at 120 francs per tonne CO$_2$ if the CO$_2$ emissions from thermal fuels in 2016 exceed 76 percent of 1990 emissions.”
In 2012, the CO\textsubscript{2} Ordinance specified “The levy shall be increased as follows:

- from 1 January 2014: at 60 francs per tonne CO\textsubscript{2}, if the CO\textsubscript{2} emissions from thermal fuels in 2012 exceed 79 percent of 1990 emissions;
Real World: Swiss Carbon Tax on Thermal Fuels

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In 2012, the CO₂ Ordinance specified “The levy shall be increased as follows:

- from 1 January 2014: at 60 francs per tonne CO₂, if the CO₂ emissions from thermal fuels in 2012 exceed 79 percent of 1990 emissions;
- from 1 January 2016:
  - at 72 francs per tonne CO₂ if the CO₂ emissions from thermal fuels in 2014 exceed 76 percent of 1990 emissions,
  - at 84 francs per tonne CO₂ if the CO₂ emissions from thermal fuels in 2014 exceed 78 percent of 1990 emissions;
- from 1 January 2018:
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  - at 120 francs per tonne CO₂ if the CO₂ emissions from thermal fuels in 2016 exceed 76 percent of 1990 emissions.”
Real World: Swiss Carbon Tax on Thermal Fuels

![Graph showing the relationship between Carbon Dioxide Levy and Thermal Carbon Dioxide Emissions (adjusted) relative to 1990 over the years from 1990 to 2018. The graph illustrates the increase in Carbon Dioxide Levy and the decrease in emissions over time.](image-url)
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- Emissions Certainty Mechanisms
- Reduced-Form Model of Emissions with Uncertainty
- Quantifying Emissions Uncertainty
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- Comparing Tax Adjustment Mechanisms
Reduced-Form Model

Extension of basic model in Metcalf (2009):
Projections of GDP and emissions intensity
Log-linear time trend for elasticity; scaling parameter

\[
\tilde{Y}_t = (1 + \gamma)^t \tilde{Y}_0 \tag{1}
\]

\[
\log Y_t - \log \tilde{Y}_t = \rho_y (\log Y_{t-1} - \log \tilde{Y}_{t-1}) + \varepsilon^y_t \tag{2}
\]

\[
\log(\frac{E_t}{Y_t}) = \frac{E_0}{Y_0} + \beta_1 t + (\beta_2 + \beta_3 \log(t)) \log(1 + \frac{P_t}{c}) + u_t \tag{3}
\]

\[
 u_t = \rho^u u_{t-1} + \varepsilon^u_t \tag{4}
\]

\[
P_t = (1 + \alpha)^{t-1} P_1 + f(E_t) \tag{5}
\]
Reduced-Form Model

Trend Uncertainty

\[ \bar{Y}_t = (1 + \gamma)^t \bar{Y}_0 \]  
(1)

\[ \log Y_t - \log \bar{Y}_t = \rho_y (\log Y_{t-1} - \log \bar{Y}_{t-1}) + \epsilon_t^y \]  
(2)

\[ \log(\frac{E_t}{Y_t}) = \frac{E_0}{Y_0} + \beta_1 t + (\beta_2 + \beta_3 \log(t)) \log(1 + \frac{P_t}{c}) + u_t \]  
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(4)

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(5)
Reduced-Form Model

Trend Uncertainty

\[ \tilde{Y}_t = (1 + \gamma)^t \tilde{Y}_0 \]  

\[ \log Y_t - \log \tilde{Y}_t = \rho_y (\log Y_{t-1} - \log \tilde{Y}_{t-1}) + \varepsilon^y_t \]  

\[ \log \left( \frac{E_t}{Y_t} \right) = \frac{E_0}{Y_0} + \beta_1 t + (\beta_2 + \beta_3 \log(t)) \log(1 + P_t/c) + u_t \]  

\[ u_t = \rho^u u_{t-1} + \varepsilon^u_t \]  

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Cyclical Uncertainty
Reduced-Form Model

Trend Uncertainty
Cyclical Uncertainty
Price Elasticity Uncertainty

\[
\bar{Y}_t = (1 + \gamma)^t \bar{Y}_0
\]  
(1)

\[
\log Y_t - \log \bar{Y}_t = \rho_y (\log Y_{t-1} - \log \bar{Y}_{t-1}) + \varepsilon_t^y
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u_t = \rho^u u_{t-1} + \varepsilon_t^u
\]  
(4)

\[
P_t = (1 + \alpha)^{t-1} P_1 + f(E_t)
\]  
(5)
• Trend parameters $\beta_1$ and $\gamma$
  • EIA AEO 2017 estimates for 2017-2050
• Price elasticities $\beta_2$ and $\beta_3$ and constant term $c$
  • Fit long-run elasticity and constant term to steady-state output from E3 CGE model
  • Fit short-run elasticity, holding constant term fixed, to transition output from Goulder-Hafstead E3 CGE model
Reduced-Form Model: Evaluating Price Elasticity Fit
Reduced-Form Model: Evaluating Price Elasticity Fit

Energy-Related Carbon Dioxide Emissions (Billion Metric Tons)

Year

E3  Fitted Reduced-Form
Reduced-Form Model: Calibrating Uncertainty

- **Trend Uncertainty**
  - Normal distribution
  - Choose std. dev. such that confidence interval matches AEO confidence intervals

- **Cyclical Uncertainty**
  - Calibrate to match historical (1973-2017) fluctuations

- **Price Elasticity Uncertainty**
  - Log-normal distribution ($\beta_2$ and $\beta_3$)
  - Choose std. dev. to generate plausible confidence intervals
  - Alternatives include: Abrell and Rausch (2017), EMF32, others?
Intro
Emissions Certainty Mechanisms
Reduced-Form Model of Emissions with Uncertainty
Quantifying Emissions Uncertainty
Defining Emissions Certainty
Comparing Tax Adjustment Mechanisms
$0 Carbon Tax Case: Annual US Emissions

Energy-Related Carbon Dioxide Emissions (Billion Metric Tons) vs. Year

Hafstead and Williams (2018)
$0 Carbon Tax Case: Cumulative US Emissions

$44 @ 5% Carbon Tax Case: Annual US Emissions

Energy-related Carbon Dioxide Emissions (Billion Metric Tons) vs. Year

$44 @ 5\%$ Carbon Tax Case: Cumulative US Emissions

Hafstead and Williams (2018)
Without a carbon tax
- Cyclical variation drives short-term uncertainty
- Trends drive long-term uncertainty

With a carbon tax
- Uncertainty in the elasticity of emissions intensity with respect to the price dominates other sources of uncertainty
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- Quantifying Emissions Uncertainty
- **Defining Emissions Certainty**
- Comparing Tax Adjustment Mechanisms
Defining Emissions Certainty

Philosophical Questions
- What do the environmentalists want to be certain about?
- Should we take into consideration the damage function?

Practical Questions
- Annual emissions or cumulative emissions?
- What moment(s) of the distribution do we compare?
Cumulative Emissions Distribution: Examples

Hafstead and Williams (2018)
Cumulative Emissions Distribution: Examples

Cumulative Emissions 2017-2050, Billion Metric Tons

Density

Cumulative Emissions 2017-2050, Billion Metric Tons

Hafstead and Williams (2018)
Cumulative Emissions Distribution and TAM

Cumulative Emissions 2017-2050, Billion Metric Tons

Density

Tax
One-Sided TAM
Cumulative Emissions Distribution and TAM

Cumulative Emissions 2017-2050, Billion Metric Tons

- **Tax**
- **One-Sided TAM**
- **Two-Sided TAM**
Defining Emissions Certainty

Philosophical Questions
- What do the environmentalists want to be certain about?
  - Avoid high emissions outcomes
- Should we take into consideration the damage function?
  - Yes we should, but we need more info on shape of damage curves

Practical Questions
- Annual emissions or cumulative emissions?
- What moment(s) of the distribution do we compare?
  - Normalize the 97.5th percentile to be within x% of goal using size of adjustment
  - Compare various moments
Outline

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- Comparing Tax Adjustment Mechanisms
Comparing Tax Adjustment Mechanisms

- Alternative mechanism design
- Examples of TAM’s in practice
- Comparison across mechanisms: A Monte Carlo experiment
Alternative Mechanism Design from Hafstead et al.

- Rules vs. Discretion
- Control Period
- Targets and Benchmarks
- Types of Adjustments
- Frequency and Size of Adjustments
- Adjustment Trigger
Alternative Mechanism Design from Hafstead et al.

- Rules vs. Discretion
Alternative Mechanism Design from Hafstead et al.

- **Rules** vs. **Discretion**
- **Control Period** 2018-2050
Alternative Mechanism Design from Hafstead et al.

- **Rules vs. Discretion**
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Hafstead and Williams (2018)
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  - Growth rate “penalty”
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- **Adjustment Trigger**
  - One Sided vs. Two Sided
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- **Frequency and Size of Adjustments**
  - 2 or 5 years
  - Define stringency with size of adjustments
- **Adjustment Trigger**
  - One Sided vs. Two Sided
  - Alternative Thresholds
Example: $44 \times 5\%$ Carbon Tax, No TAM

(a) Emissions

(b) Price

Bad Draw

Good Draw
Example: $44 @ 5% Carbon Tax, TAM

Central case benchmark path (annual emissions), growth rate penalty (5%), 5 years, One-Sided

(a) Emissions

(b) Price

Bad Draw
Good Draw
Central case benchmark path (annual emissions), growth rate penalty (5%), 5 years, Two-Sided

(a) Emissions
(b) Price

Bad Draw

Good Draw
Straight-line benchmark path (annual emissions), growth rate penalty (5%), 5 years, One-Sided

(a) Emissions

(b) Price

Bad Draw
Good Draw
Example: $44 @ 5% Carbon Tax, TAM

Straight-line benchmark path (annual emissions), growth rate penalty (5%), 5 years, Two-Sided

(a) Emissions

(b) Price

Bad Draw
Good Draw
Mechanism Comparison

Key questions

- How do the additional expected costs vary across mechanisms?
- What are the trade-offs across mechanisms?
- Do some mechanisms Pareto dominate others?
Cost vs Emissions (mean)

Hafstead and Williams (2018)
Key questions

- How do the additional expected costs vary across mechanisms?
  - Considerably

- What are the trade-offs across mechanisms?
  - Mechanisms that are more costly at reducing “right-side” risk may have lower average emissions (or higher probability of meeting projected cumulative emissions goal)

- Do some mechanisms Pareto dominate others?
Mechanism Comparison: Details

- Alternative benchmark paths
- Type of Adjustment
- Frequency of Adjustment
- One-side vs Two-sided
Cost vs Emissions (97.5th percentile): Adj. Path

- Central Case ($44 Tax)
- Straight Line (80% by 2050)
Cost vs Emissions (mean): Adj. Path

- Central Case ($44 Tax)
- Straight Line (80% by 2050)
Cost vs Emissions (target): Adj. Path

- Central Case ($44 Tax)
- Straight Line (80% by 2050)
Mechanism Comparison: Details

- Alternative benchmark paths
  - Central case path Pareto dominates straight-line path
- Type of Adjustment
- Frequency of Adjustment
- One-side vs Two-sided
Cost vs Emissions (97.5th percentile): Type of Adj.

- Discrete
- Growth Rate
Cost vs Emissions (mean): Type of Adj.

Discrete

Growth Rate
Cost vs Emissions (target): Type of Adj.

![Cost vs Emissions Graph]

- Discrete
- Growth Rate

Cumulative Cost (Mean) vs Cumulative Emissions 80% below 2005 Levels

Hafstead and Williams (2018)
Mechanism Comparison: Details

- Alternative benchmark paths
  - Central case path Pareto dominates straight-line path
- Type of Adjustment
  - Discrete adjustments seem to dominate growth rate penalties
- Frequency of Adjustment
- One-side vs Two-sided
Cost vs Emissions (97.5th percentile): Frequency
Cost vs Emissions (target): Frequency

Hafstead and Williams (2018)
Mechanism Comparison: Details

- Alternative benchmark paths
  - Central case path Pareto dominates straight-line path
- Type of Adjustment
  - Discrete adjustments seem to Pareto dominate growth rate penalties
- Frequency of Adjustment
  - More frequent adjustments are more cost-effective given 97.5 percentile target
  - Less frequent adjustments may lead to lower emissions
  - Unclear if there is Pareto dominance
- One-side vs Two-sided
Cost vs Emissions (97.5th percentile): One vs. Two Sided

Cumulative Cost (Mean) vs. Cumulative Emissions (97.5th Percentile)

- [1,0] (Green dots)
- [1,1] (Orange dots)
Cost vs Emissions (mean): One vs Two Sided

Hafstead and Williams (2018)
Cost vs Emissions (target): One vs Two Sided

Cumulative Emissions 80% below 2005 Levels

Hafstead and Williams (2018) Emissions Certainty Mechanisms 40/42
Mechanism Comparison: Details

- Alternative benchmark paths
  - Central case path Pareto dominates straight-line path

- Type of Adjustment
  - Discrete adjustments seem to Pareto dominate growth rate penalties

- Frequency of Adjustment
  - More frequent adjustments are more cost-effective given 97.5 percentile target
  - Less frequent adjustments may lead to lower emissions
  - Unclear if there is Pareto dominance

- One-side vs Two-sided
  - Two-sided adjustments are far more cost-effective given 97.5 percentile target
  - Two-sided adjustments are much less likely to hit projected emissions target
Conclusion

Using a new reduced-form model, we
- quantify emissions uncertainty under a carbon tax
- perform a comprehensive quantitative analysis of tax adjustment mechanisms

We find
- emissions uncertainty is potentially large
- tax adjustment mechanisms can reduce right-side risk at a moderate expected cost
- trade-offs exist across mechanisms