Rethinking Demand Technology Representation

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2008 Developments

Joined Dept of Civil, Construction, and Environmental Engineering at North Carolina State Unversity

Started to build a research program centered on energy modeling

Assembled a computing cluster consisting of 11 nodes with 88 processors and 1.8 TB of storage

Single region version of MARKAL successfully ported to Linux

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Goals

Analyze system-wide response to energy and environmental policy with a focus on rigorous treatment of uncertainty

I want to simplify and streamline the modeling process as much as possible.

1. Minimize data maintenance
2. Shallow learning curve to increase productivity
3. Speed model iteration and reduce data storage

Can we simply representation of commercial and residential sectors in the EPA MARKAL databases?

Current Representation in the EPA NMD

Commercial Sector

13 end-use demands
8 fuels
274 technologies
(e.g., 14 ventilation techs; 4% of total commercial demand)

Residential Sector

8 end-use demands
7 fuels
196 technologies
(e.g., 9 refrigerator techs; 2% total residential demand)

Data derived from AEO technology equipment description files for the commercial and residential sectors in NEMS

NEMS Use of COM and RES Sectors

AEO analysis of COM and RES focuses on:

- Changes in service demands (warmer climate; population shifts)
- Changes in energy consumption (demand growth; efficiency benefits)
- Relative shares and growth rates of fuel consumption
- Uptake of more efficient / renewable technologies
- Delivered energy per household and per capita
- Effect of energy prices on energy intensity

Implicit assumption that such technology detail required to make accurate projections

Hypothesis: Technology detail unwarranted by uncertainty considerations and unnecessary to make these high-level projections

Technology Detail

In bottom-up models, there is an inclination to add more technology detail over time

But big future uncertainties and no way to validate whether an increase in the detail of input data is worthwhile

Objective:
Develop quantitative rules for simplification

Validate hypothesis by comparing results from original and simplified demand sectors

Commercial + Residential Sector Outputs

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Technology detail should be sufficient to make accurate projections of key quantities but within plausible levels of uncertainty

Quantities of interest:

- System cost
- Emissions levels (system-wide and sector-level)
- Marginal cost of emissions and fuels
- Fuel consumption
- Choice of technologies (coarse resolution)

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Aggregation Rules

Demand categories: if demand category represents less than **<u>5%</u>** of total demand, then subdivide among the misc fuel categories according to current proportions.

Fuels: maintain representation of different fuels (i.e., do not simplify by removing fuel options)
→UNLESS (1) there is no tangible benefit to the fuel (i.e., lower cost and/or emissions) AND (2) residuals are insignificant, i.e. less than **5%** of total current demand.

Technologies: Calculate annual cost of each demand technology by demand category and fuel type. If several technologies have an annual cost that differs by less than **±10%** between different versions or vintages, then condense to a single representation.

Annual Cost Calculation

Annual cost of each technology estimated as follows (m$/PJ·yr):

$$\text{ANN COST} = \text{INVCOST} \cdot \frac{\text{DISCOUNT}}{1 - (1 + \text{DISCOUNT})^{\text{LIFE}}} + \text{FIXOM} + \text{VAROM} \cdot \text{CF} + \frac{\text{FUEL COST}}{\text{EFF}} \cdot \text{CF}$$

<u>Assumed fuel cost ranges</u>:
Natural gas: 4-30 m$/PJ
Electricity: 8-70 m$/PJ
Distillate: 10-20 m$/PJ
Kerosene: 2-40 m$/PJ
LPG: 4-23 m$/PJ

Problem: ordering of technology-specific annual costs changes with the assumed fuel costs

A Set Covering Problem

Given several input sets the objective is to:

Select a minimum number of sets so that the sets you have picked contain all the elements that are contained in the input sets.

E.g., Placement of fire stations to cover a city w/ a max. 5 min response time using min. number of stations.

Can be setup as integer linear programming (ILP) model

3rd aggregation rule defined an annual cost threshold of ±10%.

Each tech can represent a set of techs within ±10% of annual cost

Find the smallest technology set such that all techs are covered.

Excel Set Covering Procedure: Lighting Example

	threshold:		10																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Tech	LHS		RHS
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	>=	1
2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	>=	1
3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	>=	1
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	>=	1
5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	>=	1
6	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	>=	1
7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	>=	1
8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	>=	1
9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	>=	1
10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	>=	1
11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	>=	1
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	>=	1
13	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	>=	1
14	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	>=	1
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	>=	1
																12			

1. Find % difference in annual cost of row tech w.r.t. column tech at both min/max fuel prices
2. Select larger annual cost difference, if difference > threshold, cell =1
3. Use solver to find min set of techs to cover all techs given threshold

Residential Aggregation

Initially

- 8 end use demands
- 219 technologies
- 39 constraints (+ 88 demand constraints)

After reduction

- 5 end use demands
- 35 technologies
- 25 constraints (+ 55 demand constraints)

Commercial Aggregation

- Initially
  - 13 end use demands
  - 283 technologies
  - 54 constraints (+ 143 demand constraints)
- After reduction
  - 9 end use demands
  - 54 technologies
  - 29 constraints (+ 99 demand constraints)

Aggregation Results

Initial Cost: $53.2 trillion

Aggregated COM Cost: $52.9 trillion

Percent difference: 0.6%

Initial Cost: $53.5 trillion

Aggregated RES Cost: $53.4 trillion

Percent difference: 0.1%

System-wide CO_2 Emissions

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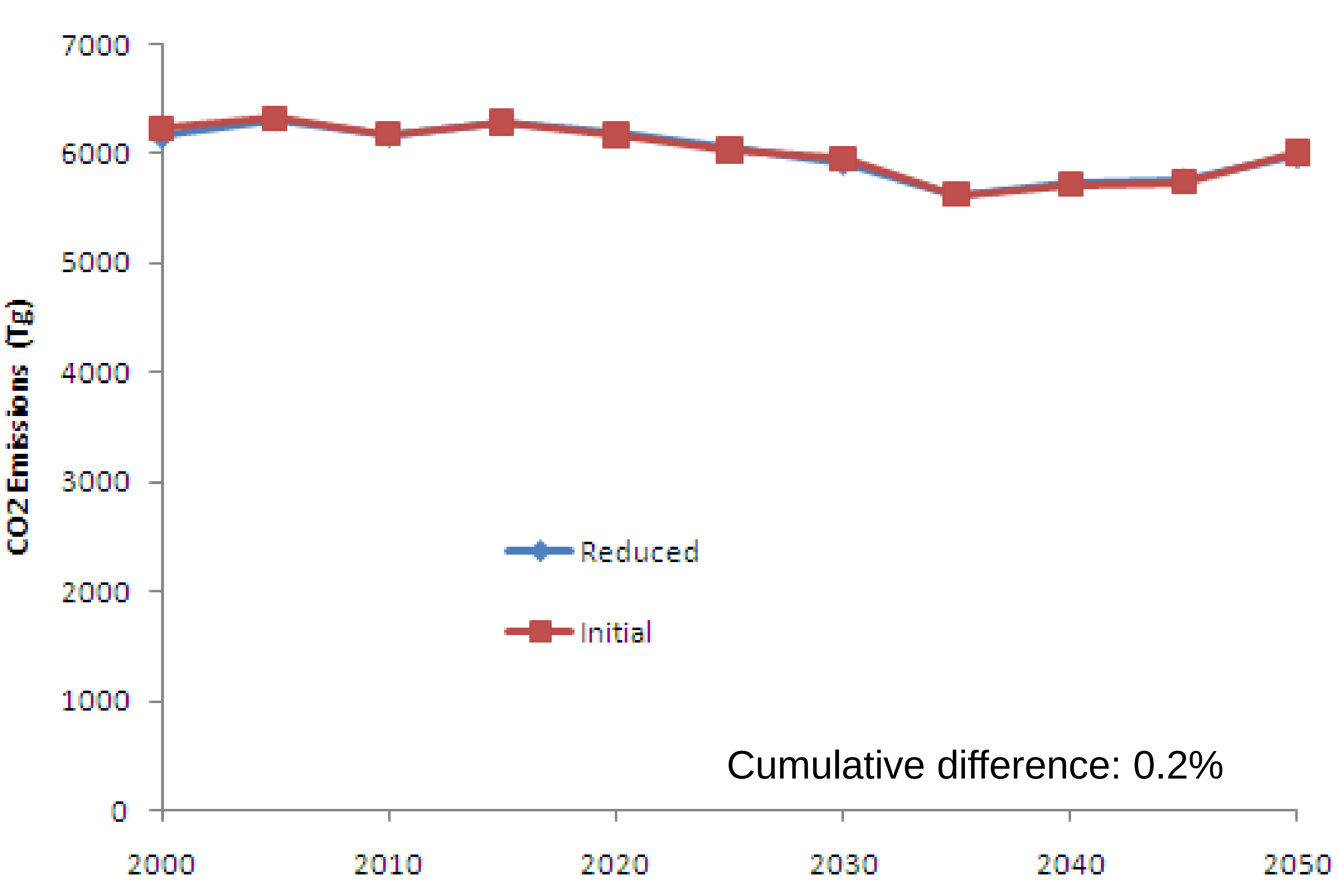
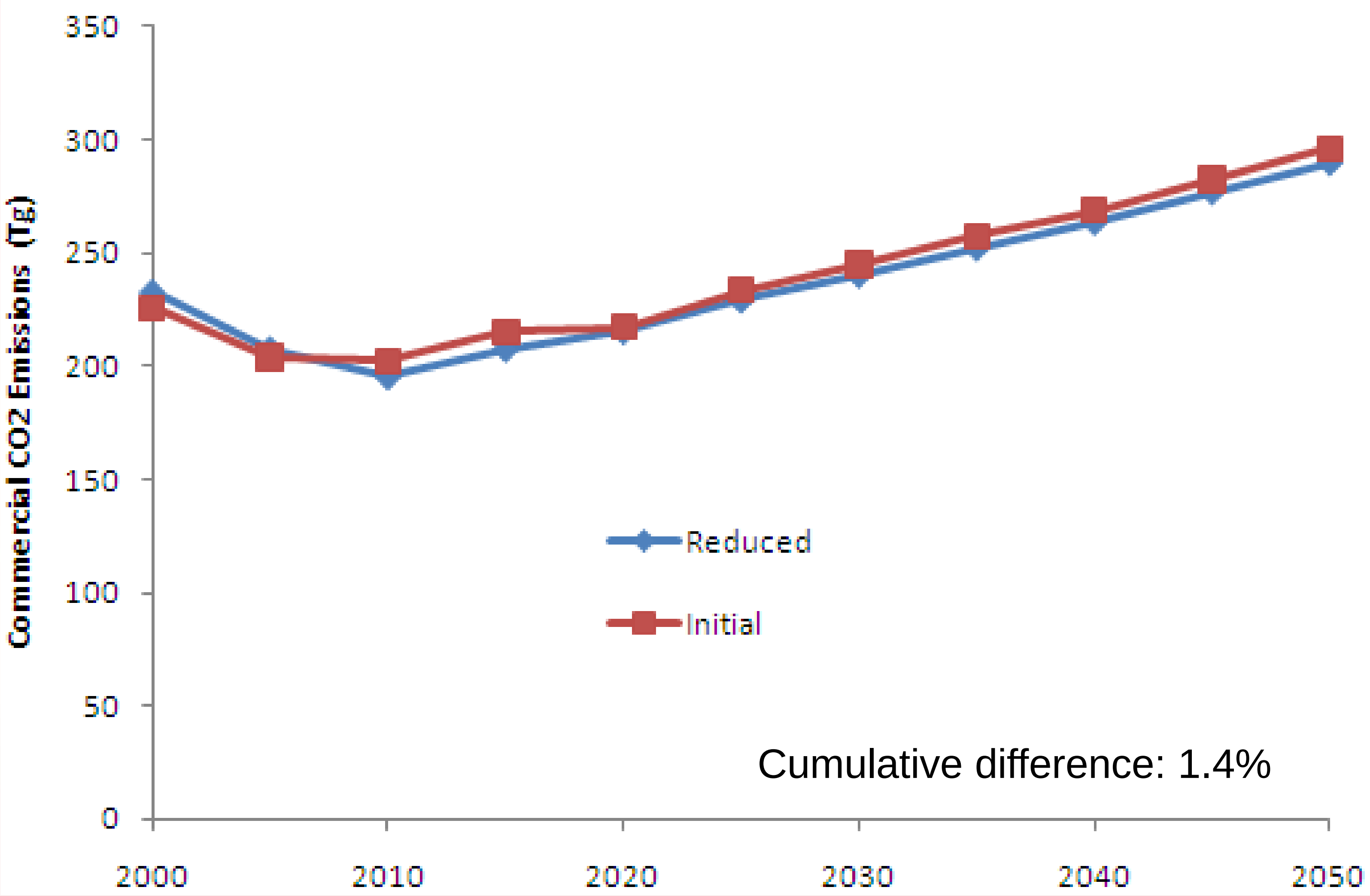
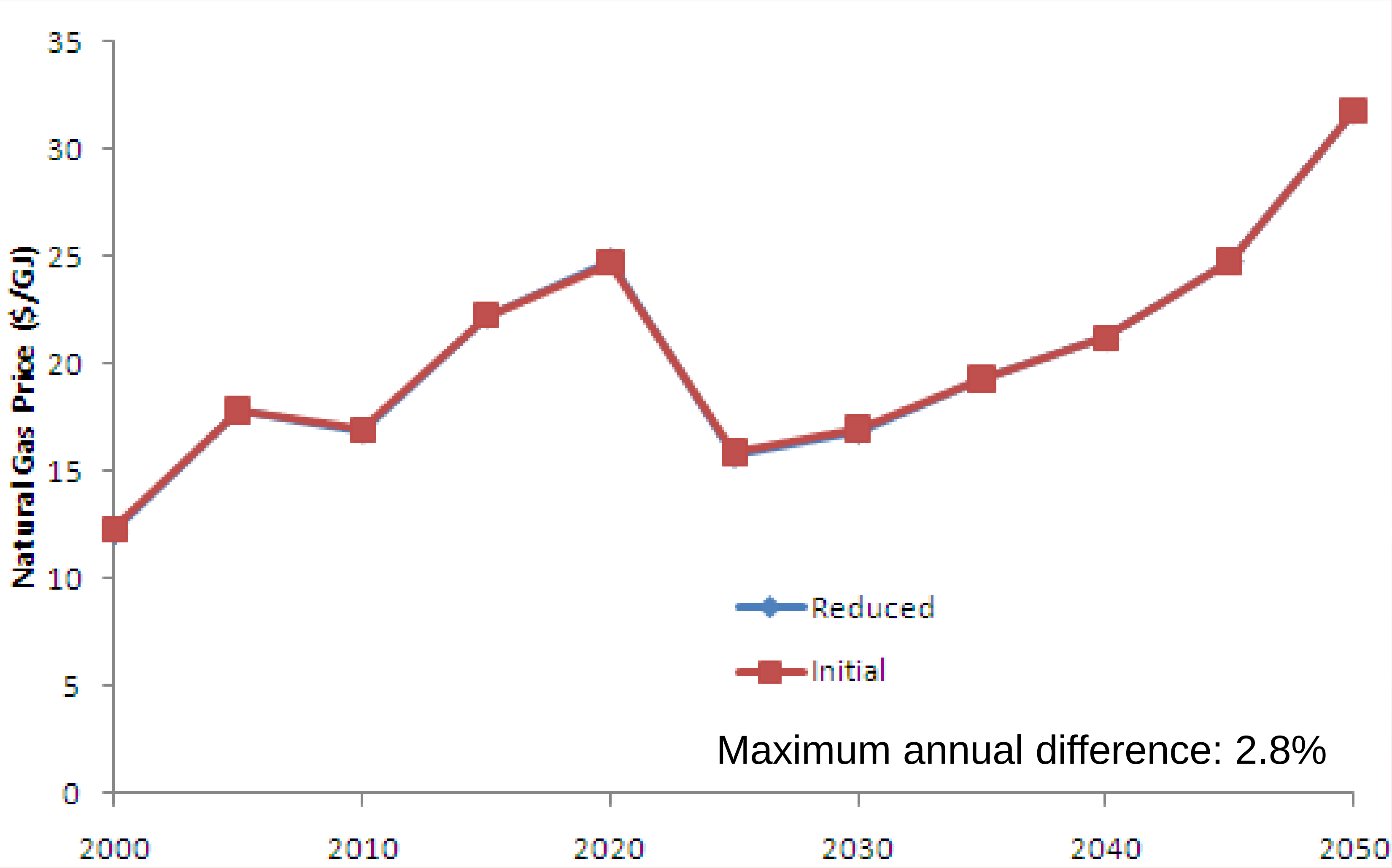


Cumulative difference: 0.2%

Commercial CO_2 Emissions



Average Natural Gas to Commercial Sector Price



Average Electricity to Commercial Sector Price

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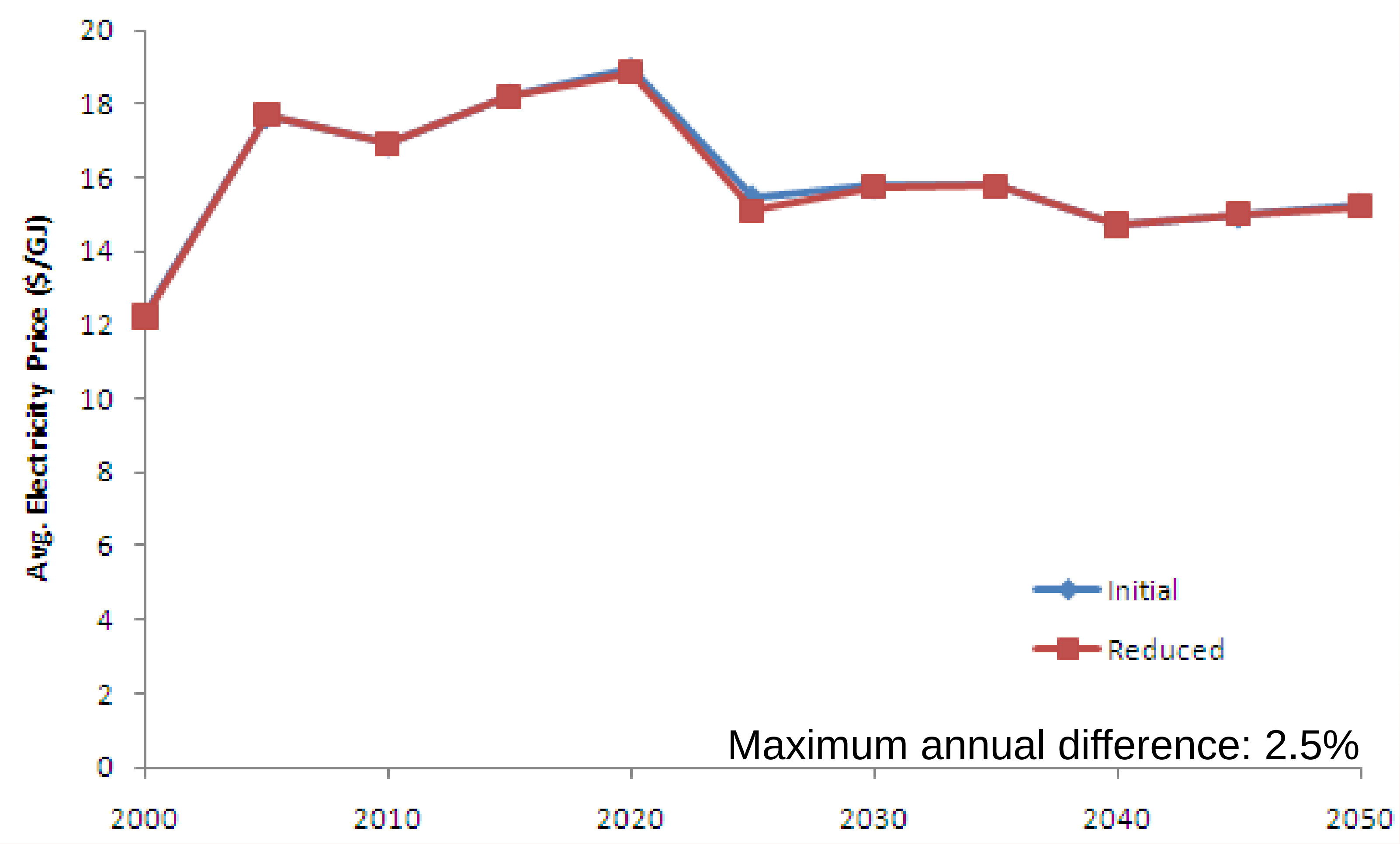

Future Work

Test robustness of representation under climate policy

Test sector performance under different decision rules and thresholds

Apply to other sectors?

Questions and Comments?

"How complex or simple a structure is depends critically upon the way in which we describe it. Most of the complex structures found in the world are enormously redundant, and we can use this redundancy to simplify their description. But to use it, to achieve the simplification, we must find the right representation."

-Herb Simon