Evaluating Economy-Wide Effects of Power Sector Regulations Using the SAGE Model

Andrew Schreiber and Dave Evans

National Center for Environmental Economics

Office of Policy, U.S. EPA

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Introduction

- For most large environmental regulations directed toward the electricity sector, EPA relies on IPM (Integrated Planning Model) to calculate compliance costs.
- What is IPM?
  - Proprietary (run by ICF) dynamic linear programming model of the electricity and primary energy sectors (coal, natural gas and refined petroleum).
  - Highly resolved in generation and pollution control technologies.
  - Fixed electricity demand and fuel demands outside electricity sector.
  - Solves for the system-wide cost of satisfying electricity demand subject to technological and regulatory constraints. *Incremental* cost of environmental regulation measured as the difference between the model's baseline and policy scenarios.
- What does IPM miss?
  - IPM does not measure social costs.
  - Does not estimate impacts in non-energy sectors nor does it estimate income/price impacts on household welfare.
  - These may be non-trivial if the regulation is large enough.

Estimating Social Costs and Economy Wide Effects

- IPM is highly valuable to understanding the possible power sector effects of a regulation. How to complement value of IPM (and similar models) with value of GE modeling?
- EPA has developed and peer reviewed the SAGE (SAGE is an Applied General Equilibrium) model to estimate social costs of environmental regulations.
  - For details, see: https://www.epa.gov/environmental-economics/cge-modeling-regulatory-analysis.
  - Currently models an aggregated electricity generation and transmission/distribution sector. Misses many of the disaggregate margins modeled in IPM.
- *How can we align the outcomes of the IPM model with SAGE to generate a social cost estimate?*
  - This work develops a methodology to link the two frameworks.

Typical Strategies for Linking Models

- Adapting IPM outputs in the SAGE framework is challenging for several reasons.
  - The IPM solution is inclusive of engineering costs of compliance and equilibrium changes in the composition of electricity generation (e.g. generation shifting), electricity prices and fuel market impacts.
  - High dimensional model with long solve times.
- Typical ways modelers have linked electricity models with CGE models:
  1. Two-way iterative link. Impractical because IPM is proprietary and run outside of the agency with high powered computer clusters.
  2. One-way link fixing electricity sector prices, quantities or expenditures in the CGE model. Assume that feedback effects are negligible (partial equilibrium solution is identical to the general equilibrium solution in energy markets).
     - Number of issues with this assumption (e.g. no demand-side impacts to electricity/energy outcomes, model differences in baseline/behavior).

Chosen "Hybrid" Approach

- To circumvent these issues, we develop a hybrid approach:
    1. Define the partial equilibrium sub-model within the CGE model that mimics, to the extent possible, margins modeled by IPM (fixing exogenous aspects of the model to the baseline – e.g. sectors not modeled, final demand).
    2. Solve for the compliance shock to the partial equilibrium sub-model that achieves the identical *incremental cost* solution as IPM.
        - Can be agnostic about differences in underlying structures and parameterization of the models.
    3. Solve the full general equilibrium model using the calibrated compliance shock. Can explicitly compare how the general equilibrium solution differs from the partial equilibrium IPM solution.

- Use the general equilibrium model with the calibrated compliance shock to estimate the social cost of the regulation.

Proof of Concept

- We've developed a proof-of-concept application of this idea using the BEIGE (Basic Economy in General Equilibrium) model.
  - Highly simplified static version of SAGE.
  - 5 sector version with energy split out (electricity, coal, natural gas, refined oil, rest of economy).
  - Discussed during consumer demand presentation earlier today.
- In this setting, we consider an illustrative mandate that requires additional/less inputs (e.g. control technologies) to the electricity sector.
  - Assume that the electricity modelers have "run" IPM and found that the incremental costs in the electricity sector of this illustrative shock is (in 2016$):
    - $200 million in capital costs, $100 million in labor costs, $69 million in natural gas expenditures, $50 million in electricity and rest of economy expenditures, $10 million in refined oil expenditures, and -$66 million in coal expenditures.

Constructing the PE Sub-model of BEIGE

- Endogenous aspects of the IPM model:
  - Electricity prices
  - Electricity input requirements (VOM, FOM, capital)
  - Electricity/coal/natural gas/refined oil trade
  - Supply and demand for electricity/coal/natural gas/refined oil, as related to the electricity sector. Primary energy inputs are only endogenized as inputs to the electricity sector
- Exogenous aspects of the IPM model, fixed in the calibration routine
  - Quantities and prices in all sectors other than electricity/primary energy
  - Fixed final demand
  - Factor prices

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Proof of Concept Calibration

```
equations
    labor_ipm(s)        incremental labor costs,
    capital_ipm(s)      incremental capital costs,
    material_ipm(ss,s) incremental material and fuel costs;

labor_ipm(ipm)$ipm_sol("l",ipm)..
    pl*(ld0(ipm)*ld(ipm) + ld_abate(ipm)*ld_abate_calib(ipm)) - ld0(ipm) =e= ipm_sol("l",ipm);

capital_ipm(ipm)$ipm_sol("k",ipm)..
    pk*(1+tk(ipm))*(kd0(ipm)*kd(ipm) + kd_abate(ipm)*kd_abate_calib(ipm)) - (1+tk0(ipm))*kd0(ipm)
    =e= (1+tk0(ipm))*ipm_sol("k",ipm);

material_ipm(ss,ipm)$ipm_sol(ss,ipm)..
    pa(ss)*(id0(ss,ipm)*id(ss,ipm) + id_abate(ss,ipm)*id_abate_calib(ss,ipm)) - id0(ss,ipm)
    =e= ipm_sol(ss,ipm);

model beige_pe_ipm /

* nest pe model statement into additional ipm constraints
      beige_pe,

* add ipm constraints
      labor_ipm.ld_abate_calib,
      capital_ipm.kd_abate_calib,
      material_ipm.id_abate_calib
  / ;
```

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Proof of Concept Validation

- We can verify that the calibrated compliance shock generates the equivalent *incremental costs* (difference between policy outcome and baseline) as what was assumed to be the IPM solution:

```
----    1117 PARAMETER calib_report

                          ipm    beige_pe

col                    -0.066      -0.066
ele                     0.050       0.050
gas                     0.069       0.069
ref                     0.010       0.010
roe                     0.050       0.050
l                       0.100       0.100
k                       0.267       0.267
backed_out_cc                      -0.432
sum_ipm_costs          -0.480
```

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Proof of Concept Results

- Unfixing the rest of the model, we can run the full GE model with the calibrated compliance costs and calculate the social costs.

---- 1298 PARAMETER incremental_costs

	ipm	pe_beige	ge_beige	ge_beige/cc	ge_beige/ipm
col	-0.066	-0.066	-0.079		
ele	0.050	0.050	-0.072		
gas	0.069	0.069	0.049		
ref	0.010	0.010	0.007		
roe	0.050	0.050	0.025		
l	0.100	0.100	0.062		
k	0.267	0.267	0.201		
compliance_cost		-0.432			
pe_cost	-0.480				
social_cost			-0.590	1.367	1.230

Next Steps

- We've worked through implementing this approach in the SAGE model. Several additional complexities we are ironing out. For instance:
  - Aligning the time horizon and regions of the SAGE model with IPM
  - New vs. existing sources
  - Treatment of taxes and subsidies
- Tons of data work that require non-standard outputs of IPM model. Also making sure we are getting the accounting right is really tricky.
  - Additional work required to reasonably decompose input composition of technology costs (e.g., labor share of new renewable capacity).
- Flesh out approach in a paper using SAGE/IPM with an illustrative shock.

Thanks!