COMPARING APPLIED GENERAL EQUILIBRIUM AND ECONOMETRIC ESTIMATES OF THE EFFECT OF AN ENVIRONMENTAL POLICY SHOCK

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Introduction

Two different approaches to evaluating large-scale environmental policies dominate contemporary literature and applied work in economics:

1. Ex ante: applied/computable general equilibrium models (CGE)
2. Ex post: econometric analysis based on reduced-form, quasi-experimental research designs
**Applied General Equilibrium Models and Economic Policy Analysis**

- CGE models provide much of the analytic background to support the development of climate policy (Carbone and Rivers, REEP, 2017).
  - British Columbia, Ontario, Quebec, Alberta climate plans
  - Waxman-Markey

- 2nd-best environmental taxation literature relies almost exclusively on CGE to quantify its findings (Goulder et al, 1997).

- Current EPA SAB subcommittee on air regs.

- Wide application in development, international trade, public finance (Shoven-Whalley, 1984).
Validating CGE models

CGE models are usually used in an ex ante setting and projections from CGE models are rarely validated against real-world experience.
Validating CGE models

![Graph showing abatement by coalition and welfare change with model types]

- Model types:
  - Non-standard
  - Standard

![Axes and data points]

- Welfare change
- Abatement by coalition

![Legend]
- Red circle: Non-standard
- Green triangle: Standard
Validating CGE models

Model types
- Non-standard
- Standard

Abatement by coalition

Output reduction by EITE sectors
Prior attempts to validate CGE models

- Kehoe (2005) evaluates CGE models of NAFTA and of Spanish entry to EU based on a simple-difference approach (before-after policy intervention).

- Valenzuela et al. (2007) assess CGE model validity by comparing results of agricultural supply shocks (weather).

- Beckman et al. (2011) assess CGE model validity by comparing results of petroleum market supply and demand shocks.
Prior attempts to validate CGE models

All approaches vulnerable to omitted variable bias...

- CGE counterfactual analysis — perfect experiments derived from theory.
- What actually happened is not.
Central challenge of statistical inference

Econometrics — the art of non-experimental statistical inference — has seen a revolution led by experimental and quasi-experimental research designs.

- Actual policy implementation — not experiments typically
- Quasi-experiments identify “accidents” of nature/policy that produce “comparable” control and treatment groups.
- Leads to diff-in-diff, instrumental variables, regression discontinuity designs that now dominate the program evaluation literature (Greenstone-Gayer, 2009).
External validity

Common trends

SUTVA

Suppose we wish to compare steel plants in BC and AB before and after BC carbon tax (diff-in-diff).

- BC plants become less competitive ⇒ supply curve shifts up.
- AB plants become more competitive ⇒ AB industry expands to satisfy more of the market.
- AB plants are not true controls — diff-in-diff overestimates true effect of carbon tax.
# Two Approaches to Environmental Policy Evaluation

The two approaches reflect alternative ways to address the fundamental problem of causal inference: we can’t observe treated unit in both treated and untreated states at the same time.

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Applied General Equilibrium (CGE) Analysis</strong></td>
<td></td>
</tr>
<tr>
<td>- connection to theory</td>
<td>- under-identification</td>
</tr>
<tr>
<td>- prospective policy analysis</td>
<td>- lack of transparency</td>
</tr>
<tr>
<td>- comprehensive welfare analysis</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Reduced-Form Quasi-experiments</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- connection to data</td>
<td>- common trends, SUTVA</td>
</tr>
<tr>
<td>- credible causal identification</td>
<td>- challenging to identify control units</td>
</tr>
</tbody>
</table>
Our contribution

We compare the two approaches, using a previously-implemented economy-wide environmental policy intervention as our setting.

1. Use statistical inference to validate the theory-driven predictions from a typical environment-economy CGE model.

2. Use theory to validate econometric research design — use CGE to check for likelihood of SUTVA violations.
   - Related work: Chetty (2009), Heckman (2010), Kuminoff-Pope (2014)

3. Use statistical inference to deepen empirical content of CGE model.
   - Related to indirect inference lit in macro, labor (Gourieroux et al, 1993)
**Policy setting**

- We compare the ex ante projections from a CGE model with ex post analysis from a program evaluation model.

- We focus on the implementation of the carbon tax in British Columbia. This is useful because:
  - It is a large-scale, economy-wide policy (applied to all combustion emissions). Easy to implement in a CGE model.
  - Significantly ambitious ($30/tCO$_2$) and enough time has passed since implementation (in 2008) that it should be possible to identify effect of policy in the data.
  - Only a short time passed between announcement and implementation, and implementation seems to have been driven by quasi-random events (Harrison, 2013 describes premier reading a book and taking a trip to China as instrumental to implementation). Arguably a good natural experiment.
  - It is exactly the type of policy that is recommended by policy analysts, and is routinely considered in modeling studies (e.g., IPCC reports).
The output metric we compare is sectoral employment levels.

- A focus at the sectoral level is useful for identification, as it allows us to statistically compare the response in polluting sectors compared to non-polluting sectors (adds variation in the independent variable).

- A sector-level focus is also appropriate from a policy perspective (competitiveness).

- Evaluating employment outcomes is interesting from a policy angle; employment is also measured with relatively little error.
Main findings

- Ex post — up to 15% reduction in employment in most carbon-intensive sectors and up to 5% increase in least carbon-intensive.

- Ex ante — Very similar pattern of effects predicted as measured econometrically ($\rho = 0.9$).

- No evidence of SUTVA violations.

- Using econometrics as “auxiliary model” to calibrate CGE suggests somewhat higher trade elasticities warranted.
**CGE Model**

- We use EC-PRO: multi-region (province), multi-sector, static, calibrated general equilibrium model.

- The model is “standard” - similar to many others used for policy analysis.

- Production is by constant returns to scale producers, operating under perfect competition.

- Trade is modeled using Armington approach. Canada is a small open economy.

- Elasticities are drawn from econometric sources where possible.

- Labour perfectly mobile across sectors, immobile across provinces. A portion of capital is perfectly mobile across sectors and provinces (a portion is fixed).
Econometric models

- We evaluate the impact of the BC carbon tax on sector employment using a difference-in-difference approach with a treatment intensity indicator, where treated (i.e., carbon taxed) sector-region-year observations are compared to untreated sector-region-year observations.

- The treatment intensity varies according to the benchmark GHG intensity of the treated sector:

$$\ln L_{ijrt} = \beta_1 (EI_{jr} \times \tau_{rt}) + \beta_2 \tau_{rt} + \lambda^1_{ijr} + \lambda^2_{ijt} + \epsilon_{ijrt}$$

\[ ^2 i – industry; j – sector; r – region; t – year; \tau – carbon tax. \]
BENCHMARK DATA
Counterfactuals from CGE model

- Replicate actual policy (and revenue-recycling) as closely as possible.

![Graph showing change in employment and value of output]
## Main regression results

<table>
<thead>
<tr>
<th>lnL</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carbon × Tax</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.00109</td>
<td>-0.00309</td>
<td>-0.00354</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.00940)</td>
<td>(0.0129)</td>
<td>(0.0126)</td>
</tr>
<tr>
<td></td>
<td>Tax</td>
<td>-0.000606</td>
<td>0.00105</td>
<td>0.00213</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.00249)</td>
<td>(0.00229)</td>
<td>(0.00440)</td>
</tr>
<tr>
<td></td>
<td>Observations</td>
<td>4,181</td>
<td>4,181</td>
<td>4,181</td>
</tr>
<tr>
<td></td>
<td>R-squared</td>
<td>0.872</td>
<td>0.880</td>
<td>0.834</td>
</tr>
<tr>
<td></td>
<td>Time FE</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Industry FE</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Province FE</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Industry × time FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Province trends</td>
<td></td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Industry × province FE</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Standard errors clustered by province × industry are in parentheses

*** p<0.01, ** p<0.05, * p<0.1
Counterfactuals from regression estimates

- We construct counterfactuals from econometric estimates, using regression coefficients.  

\[ \Delta \hat{L}_i = \exp(30 \times (\hat{\beta}_1 \times EI_i + \hat{\beta}_2)) - 1 \]

\( ^3 \)Example: \( \Delta \hat{L}_i = \exp(30 \times (\hat{\beta}_1 \times EI_i + \hat{\beta}_2)) - 1 \)
Comparison of models

<table>
<thead>
<tr>
<th></th>
<th>unweighted</th>
<th>weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sign concordance</td>
<td>0.81</td>
<td>0.98</td>
</tr>
<tr>
<td>Correlation</td>
<td>0.86</td>
<td>0.95</td>
</tr>
<tr>
<td>Linear regression</td>
<td>0.83</td>
<td>0.81</td>
</tr>
</tbody>
</table>

**Table:** Comparison between sector-level econometric and CGE predictions for the effect of a carbon tax. Weighted coefficients adopt benchmark sector output as weights.
Comparison of results
Econometric model robustness: SUTVA

- Econometric model compares treated units (industries in BC) to untreated units. Assumes no effect of treatment on untreated units (SUTVA).
- We explore this assumption using the CGE model:
  1. Implement the carbon tax in the CGE model.
  2. Estimate econometric model based on pseudo-data from CGE model.
  3. Purge CGE data of any contamination effects.
  4. Re-estimate model and compare to 2. above. If SUTVA is important, regression results will be different.
- The CGE results suggest that SUTVA violations are not a problem in this context.
## SUTVA pseudo-regressions

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) lnL</th>
<th>(2) lnL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax</td>
<td>0.0004**</td>
<td>0.0004*</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>Tax $\times$ intensity</td>
<td>-0.0046***</td>
<td>-0.0044***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>Observations</td>
<td>888</td>
<td>888</td>
</tr>
<tr>
<td>R-squared</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Year-sector FE</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Sector-region FE</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>** Robust standard errors in parentheses **</td>
<td></td>
</tr>
<tr>
<td></td>
<td>*** p&lt;0.01, ** p&lt;0.05, * p&lt;0.1</td>
<td></td>
</tr>
</tbody>
</table>
Econometric model validity: Functional forms

- Econometric model is based on a particular functional form: impact of the carbon tax is log-linear in emissions intensity.

- We explore this assumption using the CGE model:
  - Using pseudo-data generated from the CGE model, we test for alternative functional forms (higher-order terms, non-parametric).
  - We test whether sector trade intensity helps to predict sector employment impact of carbon tax.
  - We test alternative measures of emissions intensity.

- In each case, the CGE model suggests that our baseline econometric specification is preferred relative to the alternative specifications we tested.
Production functions in CGE model are nested CES functions.

Cost shares are calibrated using National Accounts input-output data. Elasticities are from econometric studies by Okagawa and Ban (2008) and Dissou, Karnizova, and Sun (2012).

We test different nesting structures estimated by OB and DKS, and compare results from OB to DKS.

Different estimates produce only small changes in CGE results.
Like most other CGE models, Armington trade specification is adopted.

Little evidence upon which to base provincial Armington elasticities (set $\sigma = 4$ based on international evidence; double for inter-provincial).

Model results are sensitive to different Armington values.

Econometric model results suggest a higher trade elasticity could be more appropriate.
CONCLUSION

- We find a high degree of similarity between sectoral employment results predicted by a ‘typical’ CGE model and a reduced-form econometric model.

- Suggests that CGE models provide meaningful ex ante predictions of carbon policy impacts.

- Analysis suggests that there are impacts of the BC carbon tax on sectoral employment levels, with most emissions-intensive sectors reducing employment by about 10-15% in response to $30/t tax, alongside expansions in less carbon-intensive sectors.

- Use of econometric estimates to calibrate/estimate CGE model provides a framework for prospective analysis/welfare analysis with a deeper empirical foundation.