SOURCE ATTRIBUTION OF AIR POLLUTION ABATEMENT HEALTH BENEFITS

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October 26, 2011
What are the impacts of *specific* emission sources on:

- Climate change (GHGs)?
- **Air quality and human health (criteria pollutants)?**
  - Sensitivity questions by nature

- Backward (adjoint) sensitivity modeling can provide an answer if health benefit assessment tools are integrated with air quality modeling
• Background
  Estimating health benefits
  Adjoint sensitivity analysis

• Results
  Health benefit sensitivities

• Potential policy applications
HEALTH BENEFITS IN CANADA

Air Quality Benefits Assessment Tool (AQBAT)

- Criteria Air Contaminants: \( \text{PM}_{2.5}, \text{O}_3, \text{NO}_2, \text{SO}_2, \text{CO} \)

- Monetary valuation of health endpoints to allow for benefit-cost analysis → dollar benefits

(Modified from Health Canada, 2008)
Estimating the impacts of individual sources on human health

Backward (Adjoint) Analysis

Sensitivity: \[
\frac{\delta y_j}{\delta x_{1,N}}
\]

- Sensitivity of a small number of outputs with respect to a large number of inputs
- Receptor-based but differentiates between source impacts
MAKING USE OF ADJOINT SENSITIVITIES

Sensitivity of what?
- Mortality in Canada (integrated across receptors)

Sensitivity to what?
- Anthropogenic NO\textsubscript{X} emissions at each location

AQBAT Sensitivity: \( \frac{\Delta \$}{\Delta C} \)

CMAQ-Adjoint Sensitivity: \( \frac{\Delta C}{\Delta E} \)

→ Combined Sensitivity: \( \frac{\Delta \$}{\Delta E} \)
ADJOINT TERMS

Adjoint cost function:

\[ J = Mortality = M \]
\[ J = \sum_{i,j=1}^{N} \left( M_{0i,j} \cdot POP_{i,j} \cdot \left( \beta_{O3} \Delta C_{i,j} + \beta_{NO2} \Delta C_{NO2i,j} \right) \right) \]

Adjoint forcing term:

\[ \frac{\Delta M}{\Delta C} \approx \frac{\delta J}{\delta C} = M_0 \cdot POP \cdot \beta \]

VSL = $5.5M (2007 CAD)

\[ \beta_{O3} = 8.39 \cdot 10^{-4} \, ppb^{-1} \quad \text{1-hr maximum} \]
\[ \beta_{NO2} = 7.48 \cdot 10^{-4} \, ppb^{-1} \quad \text{24-hr average} \]
Continental domain

- 36 km resolution
- 13 vertical layers
- Gas-phase CMAQ-Adjoint
- July-September 2007 modeling period (90 days)
SENSITIVITY RESULTS
DAILY HEALTH BENEFITS: O$_3$

MAX = $33.8$ M/DAY, MONTREAL
DAILY HEALTH BENEFITS: NO$_2$

MAX = $32.5$ M/DAY, TORONTO
TOTAL DAILY HEALTH BENEFITS

MAX: $41.7M/DAY, MONTREAL
ATLANTA & HOUSTON = $1.1M/DAY, LOS ANGELES = $0.6M/DAY
VARIABILITY IN HEALTH BENEFITS

MAPS SHOWING VARIABILITY IN HEALTH BENEFITS:

1. MAX = $42M/day, MONTREAL
2. MAX = $245M/day, TORONTO
3. MAX = $105M/day, MONTREAL
4. MAX = $275M/day, MONTREAL

The maps illustrate different regions with varying health benefits, with the maximum values indicated for each location.
DAILY UNIT REDUCTION HEALTH BENEFITS

MAX: $3,400/DAY, MONTREAL

TORONTO = $1,100/DAY, OTTAWA = $1,500/DAY
EFFECT OF AVERAGING PERIOD

1-hr Maximum $O_3$

24-hr Average $O_3$
POLICY APPLICATIONS
What are the health benefits of the Toronto subway system?

• Annual vehicle reduction (@ 11,000 miles/vehicle-yr): → 302,000

• NO\textsubscript{X} emissions reduction
  → 2,000 tonnes/yr (2007)

• $1,100 benefit/day per 1 tonne NO\textsubscript{X} reduction in Toronto

$800M benefit/yr compared to without the subway system
2. PERSONAL VEHICLES

What is the health cost associated with personal vehicles in major Canadian cities?

- 1 tonne NO\textsubscript{x}/yr \approx 110 vehicles (2007)
- Toronto: $3,800/yr per vehicle
- Ottawa: $5,000/yr per vehicle
- Montreal: $11,000/yr per vehicle
What is the Benefit-to-Permit Cost ratio for a Canadian power plant operating under NO\(_x\) cap-and-trade?

NO\(_x\) permit price in the U.S. (2009) \(\approx\) $2,000/tonne NO\(_x\)/yr

*Nanticoke Generating Station*, Ontario

\(\rightarrow\) 2,760 MW coal-fired power plant
\(\rightarrow\) 38,000 tonnes NO\(_x\)/yr emitted
\(\rightarrow\) $1,100 benefit/day per tonne NO\(_x\)

Health benefits are 200 times the cost of emissions permits!
CONCLUDING REMARKS

• Health benefits are vastly undervalued in current regulatory frameworks

• Intercontinental transport does not tell the whole story

• There is benefit to be seen from Canadian pollution control

• The source-specificity of adjoint modeling makes it very relevant to policy decision-making
FUTURE RESEARCH

• Sectoral analysis of health benefits
• Taking advantage of temporal variability in health benefit sensitivities
Acknowledgements:

Stan Judek
Health Canada

Funding:
National Science and Engineering Research Council

THANK YOU FOR YOUR ATTENTION