Energy/Environmental Analysis via B-U and T-D models:
Linking MARKAl to a macroeconometric model

Richard Loulou and Amit Kanudia
McGill U. and GERAD
richard@haloa.ca, amit@kanors.com

ABARE-ETSAP, Canberra, May 27, 2002

Map of presentation

I. Top-Down Bottom-Up model interaction

II. Case study: Kyoto Strategies for Canada

Part I: Top-Down and Bottom-Up

Requirements for detailed long term Energy-Environmental Analyses

- Ability to represent detailed energy systems
  - multiple sectors, multiple technologies, multiple regions
  - capital turnover detail
  - trade of energy and materials
- Ability to generate prices endogenously
- Ability to model main economic indicators: production, consumption, employment, interest rate
- Ability to capture main costs and benefits
- Ability to model structural changes (e.g. technological adoption,changes in behavior)

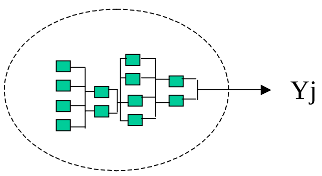
Equilibrium models

- Good at providing a coherent picture of an economy
  - prices and quantities in equilibrium
  - satisfy main economic axioms
  - clear set of rules regarding behavior of agents
- Aptitude for detail: v. good for B-U (partial equilibrium models), less so for T-D (general equilibrium models)
- Coverage of main economic variables: v. good for T-D, partial for B-U
- <u>However</u>: limitations are caused mostly by technical considerations, not by basic 'philosophical' differences

CGE models vs. B-U models: the representation of productive sectors

Top-Down $Yj = F(Lj, Kj, Ei,j)$

Bottom-up



CGE models vs. B-U models

- CGE's could *theoretically* include as much technological detail as needed. Limit arises because of algorithmic capabilities (Non-linear equations and inequations).
- Conversely, B-U models could *theoretically* coompute aggregate consumption, GDP, and aggregate capital. Again here, the limitation comes from technical considerations (non-linearity combined with large size)

Our compromise approach

Step 1: Extend B-U models as far as possible w/o hitting technical limit (i.e. keep model linear). Thus: technological detail is preserved.

Step 2: Supplement B-U results with macroeconomic model, with or without feedback link:

- with feedback: iterative scheme is time-consuming
- w/o feedback: simpler implementation, quicker cycle time

Step 1: Extending B-U models

- Price elastic demands for products and services are implemented without destroying the convexity of the B-U optimization (linearization is easy)
- Multi-regional models (with trade) capture the inter-regional interactions
- The changes in product and service outputs are better represented if the inter-industry material flows are well modeled (e.g. steel should flow into car production). This is possible, but often onerous. The extension of B-U energy models into B-U energy and materials models remedies this defect (Gielen, 2000)

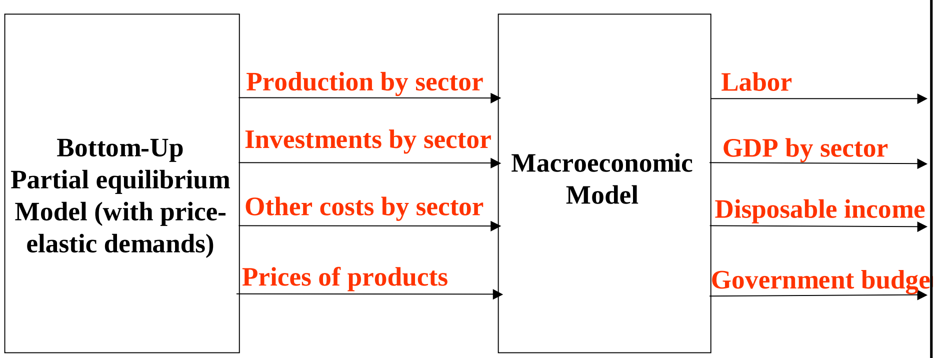
Extending B-U models

- Treatment of uncertainty: via stochastic programming, robust programming, or time-stepped model operation (total myopia)
- Additional processing of B-U results allows to compute additional economic variables

Step 2: Feeding results into macroeconomic model

- The main output from a B-U model is a detailed schedule of investments and other expenditures, and of prices, by each sub-sector, at each time-period.
- Once precisely interpreted, these parameters are input into a macroeconomic model which calculates the impacts on disposable income, on consumption, on labor and wages, interest rate, inflation, etc.
- **Key issue**: is it necessary to feed macro results back into B-U model?
- **Tentative answer**: No

Step 2: B-U / macro interaction with no feedback



Justification of Approach

- The approach (with no feedback to BU) assumes that demands for energy intensive products and services are not significantly altered in the macroeconomic model (for instance the impacts on demands of income or of government budget are neglected)
- In other words, it is assumed that the price elasticities used in the B-U model capture **most** of the variability of energy intensive demands
- There is some support for this thesis (Kram and Sheepper, 1994), but more experimentation is needed.

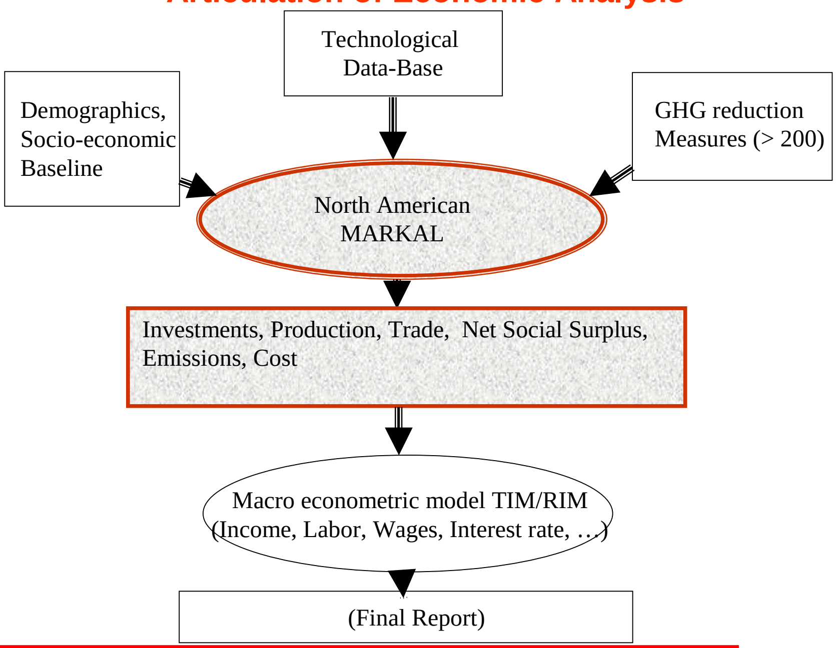
Important Issue

- What values for price elasticities of demands?

Part II: Case study

Kyoto strategies for Canada

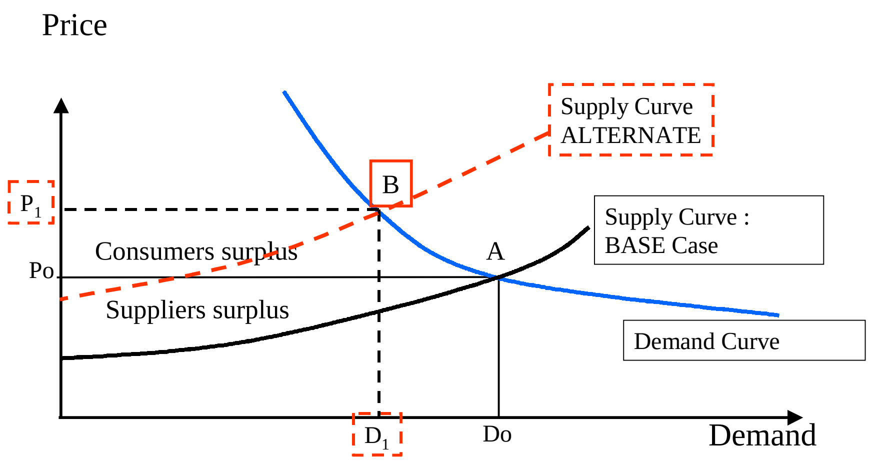
Articulation of Economic Analysis



North American MARKAL

- **Least-Cost Partial Equilibrium elastic demands MARKAL model**
- **Long-term** (45 years, reduced to 25 years for this project)
- **Integrated:** extraction, transformation, end-uses of energy and (some) materials, elastic economic demands, trade of energy.
- **Detailed** technology level (more than 10,000 technologies)
- Five GHG Gases Modeled (CO2, CH4, N2O, CxFy, SF6)
- Mainly, but **not exclusively** Energy: end-use devices and processes, Geological Sinks.
- **Multi-regional**
  - 14 linked models (13 Canadian, 1 USA)
  - Inter-regional trade of: all Oil Products, Coal, Gas, Electricity, Emission Permits.
  - Electricity interties and pipelines treated as technologies

Net Social Surplus = Consumers Surplus + Producers Surplus



Application: Kyoto scenarios for Canada

- 1990 emissions: 609 Mt CO2-e
- Kyoto target in 2010: 1990 - 6% = 571 Mt
- To-day's emissions: 1990 + 20%
- BAU emissions in 2010: 1990 + 33% = 810 Mt
- Kyoto Gap: 239 Mt

- Scenarios
  - US emits as in BAU
  - Other Annex I countries implement Kyoto reductions
  - International GHG permits (2 alt. prices \$6 or \$30/t CO2e) are accessible at int'l price.

Strategy: Permit allocation Cases

- Strategies
  - Cap-and-trade for Large Final emitters (43% of total Canadian emissions): most industries, electricity sector
  - Specific (efficient) measures for non covered sectors
- Case 2a: Domestic permits are allocated gratis in lumped, grand-fathered manner to each covered industry k

$$\mathbf{Alloc_k = Em_{k,\,1990} - 6\%}$$

- Case 2: Domestic permits are allocated gratis, proportionally to output, to each covered industry k

$$\mathbf{Alloc_k = GHG\_INT_{\,k,1990} * OUTPUT_{\,k,2010} * alpha}$$

Strategy: Permit allocation Cases

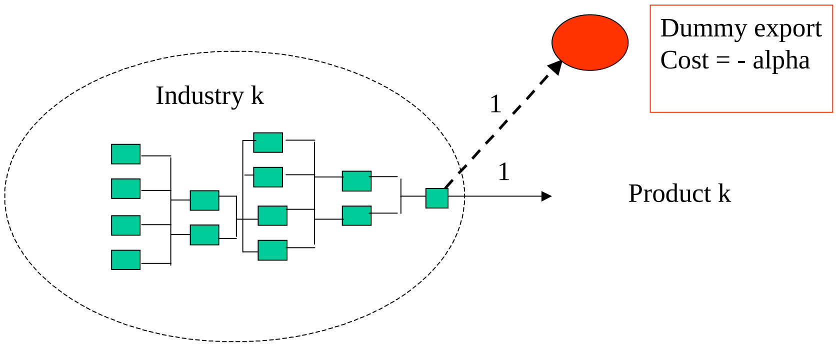
- Case 2s: same as Case 2, plus supplementarity condition: permit purchases < 50% of Kyoto Gap
- Case 3: Domestic permits are allocated gratis, proportionally to output, to each covered industry, by province, according to a Triptych formula that selectively favors certain sectors and provinces

$$\text{Alloc}_{k,n} = \text{OUTPUT}_{k,n,2010} * \text{alpha}_n$$

Lumped versus Output based allocations

- In Case 2a, lumped allocation of permits has ***no*** impact on marginal production cost, hence on prices: equilibrium is independent of allocation
- In Case 2, output based allocation has a ***direct*** impact on marginal production cost: equilibrium is influenced by allocation (permit allocation acts as an incentive to produce)
- In Case 2s: same as Case 2, but with additional constraint on permit purchase

Modeling of Output based permit allocation



Derivation of price elasticities (for use in MARKAL)

- Run macro model with base case production costs and with +10% increase in production costs
- Observe a) outputs, and b) prices, in both runs, and compute price elasticities
- Use these elasticities in MARKAL

- Several price elasticities were infinite (price-taking), e.g. P&P, Smelting, Chemicals, Cement, Primary metals.

Results: Costs (NPV, M CAD in 2000)

	C2-HIC	C2-INC	C2-LOC	C2-SLOC	C2AHIC	C2ALOC	C4_HIC	C4_LOC
INV+	-4,255	-1,366	3,358	-8,901	-68,259	-10,760	-1,961	5,261
Net Fuel cost	-7,911	-10,434	-10,459	-6,295	23,637	-11,978	-3,307	-10,469
Permit cost	9,650	11,805	7,071	5,835	-4,416	6,086	10,654	7,140
Output loss	19,570	7,012	-2,225	14,786	60,158	15,581	12,506	-3,842
Total = loss of surplus	**17,054**	**7,017**	**-2,255**	**5,425**	**11,120**	**-1,071**	**17,892**	**-1,910**

Results: industrial outputs (% change wrt to BASE)

Industry	C2-HIC	C2-INC	C2-LOC	C2-SLOC	C2AHIC	C2ALOC	C4_HIC	C4_LOC
Electricity	1%	0%	0%	13%	-16%	-4%	3%	0%
Chemicals	-1%	1%	3%	2%	-35%	-18%	-7%	4%
Gas	0%	0%	0%	0%	0%	0%	0%	0%
Iron & Steel	-4%	-4%	1%	1%	-18%	-6%	3%	1%
Mining	8%	8%	8%	8%	-20%	-5%	7%	8%
Minerals	-31%	-31%	-28%	-27%	-31%	-31%	-25%	-13%
Conv Oil	-1%	0%	0%	-1%	-1%	0%	-1%	0%
Oil Sands	0%	0%	0%	-16%	-33%	0%	0%	0%
Other indus.	-6%	-4%	0%	-3%	-10%	-4%	0%	0%
P&P	4%	6%	6%	-8%	-21%	-7%	15%	7%
Oil refining	-13%	-8%	-4%	-14%	-14%	-5%	-12%	-4%
Road transp	0%	0%	0%	-1%	0%	0%	0%	0%
Smelting	-20%	-5%	0%	-15%	-30%	-6%	-17%	0%

Results: emissions (Mt in 2010)

industry	BASE	C2-HIC	C2-INC	C2-LOC	C2-SLOC	C2AHIC	C2ALOC	C3_HIC	C3_LOC
Gas Pipelines	23	16	16	17	17	17	17	16	17
Gas extraction covered	24	23	23	23	23	23	23	23	23
Oil Sands	51	46	48	51	46	31	51	46	51
Oil Refining	25	18	19	21	20	18	21	18	22
Chemicals	21	19	19	21	21	13	16	18	20
Iron and Steel	17	16	16	17	17	14	16	17	17
Minerals	13	9	9	9	9	9	9	10	11
Mining	6	6	6	6	6	5	6	6	6
Other Industries	34	30	32	34	33	28	33	32	34
Pulp and Paper	17	14	14	17	14	12	16	15	17
Smelting	15	11	13	14	13	9	14	11	15
Electricity	126	53	102	117	144	27	108	54	118
Gas upstream uncovere	33	31	31	32	31	31	32	31	32
Upstream oil	33	25	27	27	23	23	27	25	27
Commercial	35	27	30	31	20	29	31	27	31
Residential	43	29	36	38	18	34	39	28	38
Transport	190	181	183	184	173	181	184	181	184
Landfills	24	18	18	18	18	18	18	18	18
Other Emissions	75	65	66	67	65	65	67	65	67
Forest Sink	-20	-20	-20	-20	-20	-20	-20	-20	-20
TOTAL	**786**	**618**	**690**	**725**	**691**	**567**	**709**	**621**	**728**

Results: permits purchased (Mt in 2010)

	C2-HIC	C2-INC	C2-LOC	C2SLOC	C2AHIC	C2ALOC	C4HIC	C4 LOC
Gas Pipelines	2.0	3.0	3.5	2.6	0.3	0.8	1.6	2.7
Gas extraction excep	8.6	8.9	9.2	8.1	8.0	8.1	10.2	10.4
Oil Sands	5.5	7.7	12.0	9.7	16.5	37.1	15.3	21.8
Oil Refining	7.6	8.6	10.5	9.1	1.1	4.4	4.3	6.5
Chemicals	-2.5	-2.7	-1.7	-2.6	-10.0	-6.4	-6.7	-5.5
Iron and Steel	4.0	4.2	4.8	4.0	-0.6	1.4	-0.4	-0.2
Minerals	2.8	2.9	3.1	2.7	-2.4	-2.4	1.2	1.5
Mining	-4.0	-3.7	-3.3	-3.9	-0.5	0.4	-3.0	-2.4
Other Industries	10.5	12.2	13.8	12.4	0.9	5.3	3.4	5.8
Pulp and Paper	4.5	5.3	7.6	5.6	0.9	4.8	-1.2	2.2
Smelting	5.5	7.2	8.6	7.3	1.3	5.6	3.8	6.5
Electricity	-36.7	12.0	26.2	55.0	-64.2	17.4	-42.7	20.6
CH4-Upstream - Gas	6.9	7.1	7.6	6.9	6.9	7.6	9.7	10.4
Upstream oil	0.6	2.2	3.0	-1.7	-1.7	3.0	3.3	5.7
GHG-Commercial-Mt	0.7	3.2	4.5	-6.8	2.5	4.5	3.5	7.5
GHG-Residential-Mt	-14.0	-7.1	-5.3	-25.5	-9.1	-4.0	-10.4	-0.5
GHG-Transport-Mt	40.0	41.3	42.4	32.0	40.0	42.4	56.0	58.4
Landfill GHG	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-0.4	-0.4
Other Emissions	8.6	10.0	10.8	8.6	8.6	10.8	8.9	11.1
TOTAL	**47.8**	**119.4**	**154.5**	**120.8**	**-4.1**	**137.9**	**56.2**	**162.1**

Results: GHG intensities
(% change w.r.t. to BASE)

Industry	C2-HIC	C2-INC	C2-LOC	C2-SLOC	C2AHIC	C2ALOC	C4_HIC	C4_LOC
Electricity	-59%	-19%	-8%	1%	-75%	-10%	-58%	-7%
Chemicals	-7%	-9%	-5%	-3%	-6%	-5%	-11%	-7%
Gas	-12%	-11%	-10%	-11%	-11%	-10%	-12%	-10%
Iron & Steel	-3%	-2%	-1%	0%	-1%	-1%	-2%	-1%
Mining	-9%	-6%	-6%	-7%	0%	1%	-10%	-6%
Minerals	-1%	-1%	-1%	-1%	-1%	-1%	-2%	-1%
Conv Oil	-23%	-19%	-16%	-30%	-30%	-16%	-23%	-16%
Oil Sands	-10%	-7%	0%	5%	-11%	0%	-10%	0%
Other indus.	-8%	-4%	-2%	-1%	-9%	-1%	-8%	-2%
P&P	-22%	-18%	-6%	-9%	-11%	1%	-24%	-6%
Oil refining	-16%	-15%	-9%	-6%	-15%	-9%	-15%	-9%
Road transp	-9%	-8%	-8%	-13%	-9%	-8%	-9%	-8%
Smelting	-12%	-7%	0%	4%	-13%	1%	-12%	1%

Conclusion

- B-U models (with elastic demands) may be used in coordination with macroeconomic models
- Iterating between the two models is not strictly necessary
- The interaction is not excessively complex, and requires mainly good estimates of price elasticities
- Possible improvements:
  - modeling Material flows
  - Better estimates of price elasticities, especially for exported products