EMPAX-CGE Model

Presented in EPA/OAQPS RIA Workshop

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EMPAX-CGE: Presentation Overview

- ## Background of EMPAX

- ## Overview of Existing Model

  - Description of Industries and Regions
  - General Model Structure
  - Dynamics
  - Types of Model Outputs

- ## Ongoing Extensions

  - Updates
  - Additional Industries
  - Structure
  - State-level Results
  - Global Insights forecasts of economic activity
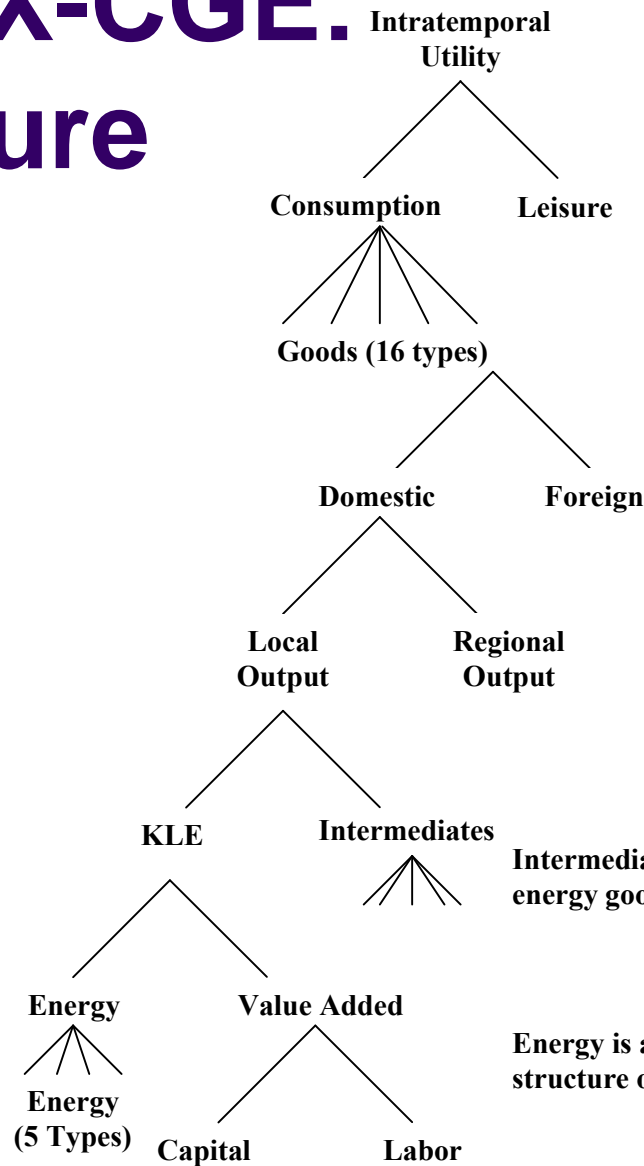
Background of EMPAX

- Predecessor model (i.e., ICCR EIA model) used for Combustion MACTs (e.g., Industrial Boiler MACT) and SAMI (Southern Appalachian Mountain Initiative) project in late '90s to 2004 timeframe
  - Largely applied a partial equilibrium approach – estimate impacts to a single or few industries or markets at a time
- Determined that multi-sector, energy market focus more appropriate with CGE model
- Previous EMPAX development effort
  - National, static version (383 sectors) – *not used*
  - Regional, static version (10 regions w/ 39 sectors) – *not used very much*
  - Regional, dynamic version (5 regions w/ 17 sectors) – *current version*
- Linked to cost models such as IPM and AirControlNet for CAIR, CAVR, PM NAAQS, and Ozone assessments (dynamic version used in each)
  - Note: still at work in determining if EMPAX will be utilized in ozone RIA due to extrapolated cost concerns – EMPAX is run with known control costs as for previous RIAs
- Underwent external peer-review in 2006, presented to SAB
- Will be used in latest Section 812 report

EMPAX-CGE: Overview of Current Model

- Dynamic regional economic model of US economy
- 5 Regions
  - Aggregation of 10 NERC regions (along state lines)
- 17 Sectors
  - 6 energy sectors
  - 8 manufacturing sectors
  - 3 non-manufacturing sectors
- Baseline conditions characterized by:
  - IMPLAN state-level economic data for 2000 (extended to 2005)
  - DOE/EIA energy data and forecasts (Annual Energy Outlook – AEO - 2003)
- Intertemporal optimization with perfect foresight
- Except dynamics, use equations from the MIT EPPA model
- Model operates using GAMS software

EMPAX-CGE: Structure

Intratemporal Utility

Consumption   Leisure

Goods (16 types)

Domestic   Foreign

Local Output   Regional Output

KLE   Intermediates

Energy   Value Added

Energy (5 Types)   Capital   Labor

Household utility within a time period is a CES function of consumption and leisure.

Consumption is a Cobb-Douglas composite of the 16 types of goods.

Each consumption good is a CES composite of foreign and domestically produced goods.

Domestic goods are a CES composite of locally produced goods and goods from other regions.

Most producer goods use fixed pro-portions of intermediate inputs and a capital-labor-energy (KLE) composite.

Intermediate materials inputs are the 11 types of non-energy goods, in fixed proportion for each industry.

The KLE composite is a CES function of energy and value-added (KL).
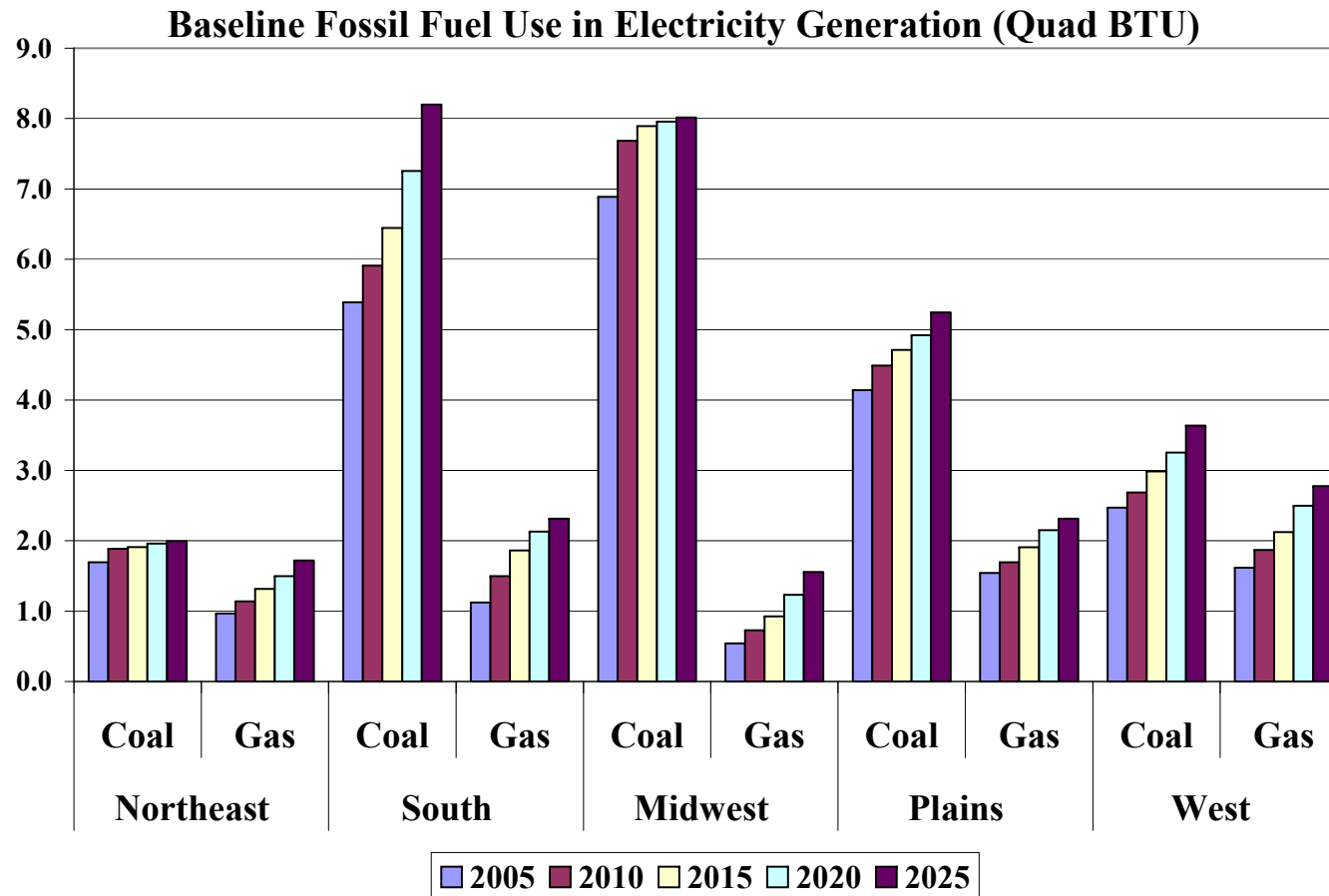
Energy is a CES composite of 5 types of fuel. The structure of this function varies across industries.

Value added is a Cobb-Douglas composite of capital and labor.

5

EMPAX-CGE: Current Regions

"West"*

"Plains"

"Midwest"

"North-east"

"Southeast"

EMPAX-CGE: Current Regional Detail

Baseline Fossil Fuel Use in Electricity Generation (Quad BTU)

Legend: 2005, 2010, 2015, 2020, 2025

Regions: Northeast, South, Midwest, Plains, West (each with Coal and Gas)

Baseline forecasts of energy production, consumption, and prices from *Annual Energy Outlook* (also output by sector and regional GDP growth)

EMPAX-CGE: Current Sectoral Detail

- ● 17 Sectors in each of 5 Regions:

Energy Production	Energy-Intensive Sectors	Others
Coal	Food	Agriculture
Crude oil	Paper	Other Manufacturing
Electricity *(fossil and nonfossil)*	Chemicals	Services
Natural Gas	Glass	Transportation
Refined Petroleum	Cement	
	Iron and Steel	
	Aluminum	

- ● All sectors are interconnected; sectors are at 2 to 4-digit NAICS level and below (except for crude oil, natural gas, and refined petroleum sectors)
- ● Model distinguishes between fossil-fired and nonfossil-fired electricity production so costs can be applied separately
- ● The 7 sectors called "energy-intensive" are defined as such by the Energy Information Administration (EIA)

EMPAX-CGE: Baseline Data Summary

- Economic and energy data sources:
  - IMPLAN state-level economic data (2000) (information on 528 industries and 9 household types)
  - EIA (AEO, MECS, State Reports, Industry Annuals)

- AEO 2003 energy and industrial output forecasts
  - Production and consumption by industry and fuel
  - Incorporate baseline energy efficiency improvements

- Natural resources (coal, crude oil, natural gas)
  - Match resource prices to AEO forecast (as feasible)
  - Set supply elasticity (from MIT/EPPA) around resulting price path
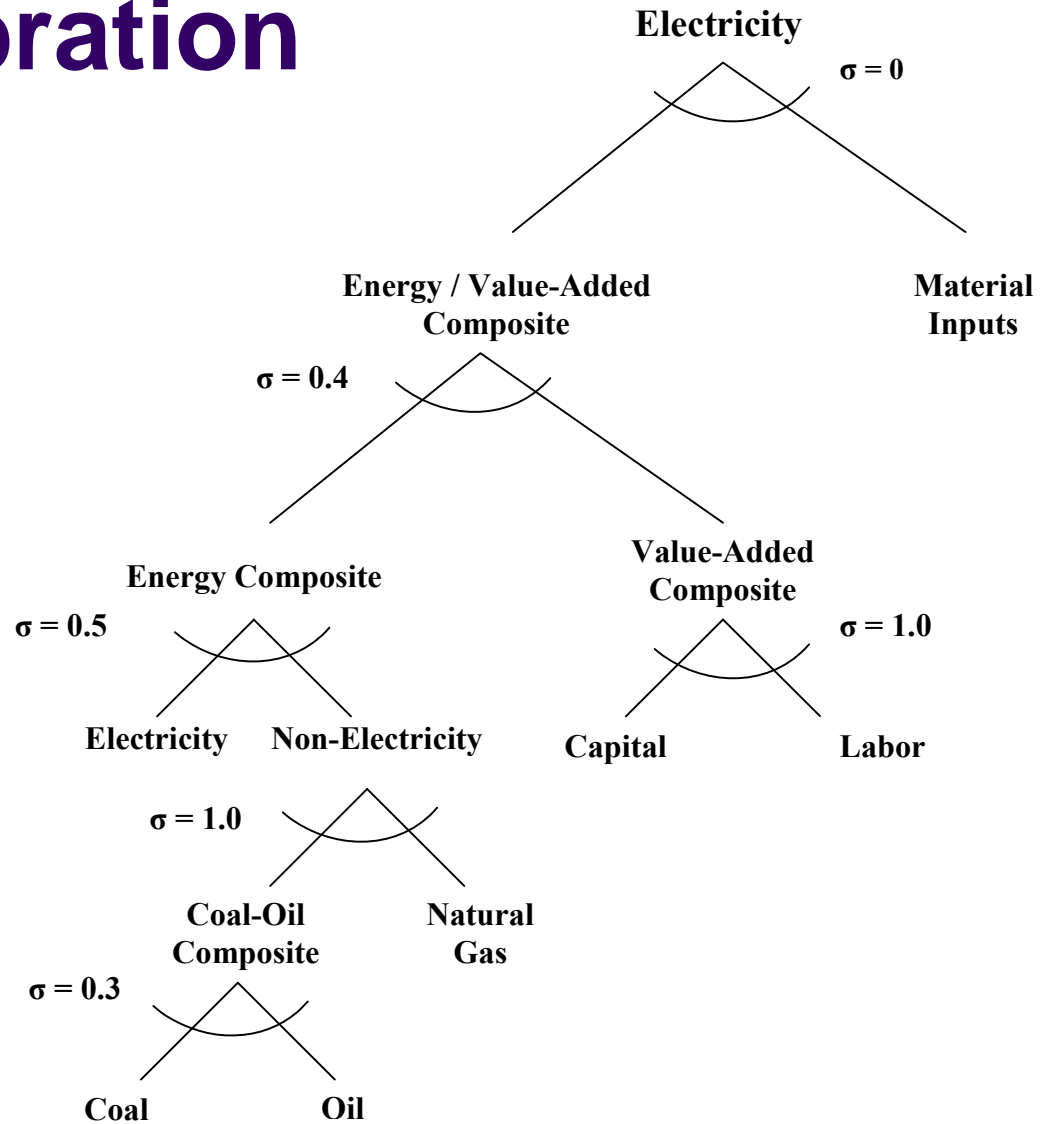
EMPAX-CGE Energy Detail
Baseline Energy Use: Northeast

Sector	Fuel (Quad Btu)	2005	2010	2015	2020	2025	Growth Rate
Residential	Electricity	0.64	0.68	0.69	0.71	0.74	0.8%
	Natural Gas	1.27	1.32	1.36	1.43	1.49	0.8%
	Oil	3.59	3.99	4.33	4.61	4.91	1.6%
	Total	**5.49**	**5.98**	**6.38**	**6.75**	**7.14**	**1.3%**
Electricity	Coal	1.69	1.89	1.91	1.96	1.99	0.8%
	Natural Gas	0.97	1.14	1.32	1.50	1.72	2.9%
	Oil	0.49	0.52	0.54	0.55	0.52	0.3%
	Total	**3.15**	**3.54**	**3.77**	**4.00**	**4.23**	**1.5%**
Petroleum Refining	Crude Oil	3.07	3.33	3.42	3.53	3.58	0.8%
	Electricity	0.01	0.01	0.01	0.01	0.01	1.5%
	Natural Gas	0.06	0.08	0.08	0.08	0.08	1.2%
	Oil	0.20	0.21	0.21	0.22	0.21	0.3%
	Total	**3.34**	**3.63**	**3.72**	**3.83**	**3.88**	**0.7%**
Agriculture	Coal	0.00	0.00	0.00	0.00	0.00	0.0%
	Electricity	0.01	0.01	0.01	0.01	0.01	0.9%
	Natural Gas	0.03	0.03	0.03	0.03	0.03	1.3%
	Oil	0.08	0.09	0.09	0.10	0.10	1.2%
	Total	**0.12**	**0.13**	**0.13**	**0.14**	**0.15**	**1.2%**
Energy-Intensive Manufacturing	Coal	0.34	0.35	0.35	0.34	0.34	0.0%
	Electricity	0.16	0.17	0.18	0.18	0.18	0.6%
	Natural Gas	1.15	1.25	1.33	1.41	1.50	1.3%
	Oil	1.28	1.43	1.58	1.69	1.81	1.8%
	Total	**2.93**	**3.20**	**3.43**	**3.62**	**3.84**	**1.4%**
Other Manufacturing	Coal	0.05	0.06	0.06	0.06	0.06	0.6%
	Electricity	0.16	0.19	0.22	0.24	0.26	2.4%
	Natural Gas	0.44	0.48	0.54	0.60	0.67	2.2%
	Oil	0.41	0.45	0.49	0.52	0.55	1.6%
	Total	**1.05**	**1.18**	**1.30**	**1.41**	**1.54**	**1.9%**
Services	Coal	0.01	0.01	0.01	0.01	0.01	0.9%
	Electricity	0.66	0.73	0.78	0.82	0.88	1.4%
	Natural Gas	0.80	0.84	0.88	0.95	1.01	1.2%
	Oil	0.24	0.25	0.25	0.26	0.26	0.3%
	Total	**1.71**	**1.83**	**1.93**	**2.04**	**2.15**	**1.2%**
Transportation	Coal	0.00	0.00	0.00	0.00	0.00	0.0%
	Electricity	0.01	0.02	0.02	0.02	0.02	1.3%
	Natural Gas	0.05	0.06	0.07	0.07	0.08	2.4%
	Oil	1.68	1.93	2.16	2.36	2.59	2.2%
	Total	**1.75**	**2.01**	**2.25**	**2.45**	**2.70**	**2.2%**
Total	Coal	2.11	2.32	2.34	2.39	2.42	0.7%
	Electricity	1.71	1.87	1.97	2.06	2.17	1.2%
	Natural Gas	4.87	5.30	5.73	6.18	6.73	1.6%
	Oil	7.98	8.88	9.67	10.31	10.98	1.6%
	Total	**16.67**	**18.37**	**19.71**	**20.94**	**22.30**	**1.5%**

EMPAX-CGE: Calibration

- Model uses nested constant elasticity of substitution (CES) equations

  - Data show inputs currently used to produce output
  - CES functions show options for and ease of substitutions
  - Allows changes in inputs and energy-efficiency improvements

- Calibrated to production functions & elasticities of MIT's CGE model, EPPA (engineering based)

- Initial model year of 2005 – balanced SAM data

- AEO forecasts (regional GDP, energy production, industrial output & energy consumption, energy prices)

EMPAX-CGE: Calibration

Electricity

σ = 0

Energy / Value-Added Composite

Material Inputs

σ = 0.4

Energy Composite

Value-Added Composite

σ = 0.5

σ = 1.0

Electricity   Non-Electricity

Capital   Labor

σ = 1.0

Coal-Oil Composite

Natural Gas

σ = 0.3

Coal   Oil

EMPAX-CGE: Intertemporal Dynamics

- Arrow-Debreu general equilibrium theory (i.e., perfectly competitive markets, firms are pricetakers) for markets that are covered in EMPAX

- Intertemporally optimizing with foresight
  - Households maximize present value (PV) of future consumption subject to budget (and time) constraints
  - Firms maximize PV of future profits subject to technology constraints

- Initial year of 2005, usually solves to 2050

- Time periods at 5-year intervals connected by savings-investment decisions of households

EMPAX-CGE: Intertemporal Dynamics

- Sources of Growth:
  - Technology change
    - Baseline includes technological progress & energy efficiency improvements from AEO forecasts
    - Increases in energy prices encourage industrial efficiency and substitution to K/L as well as household substitution to out of energy goods
  - Increases in natural resources (stocks are modeled)
  - Capital accumulation
  - Labor supply and productivity (regional GDP forecasts)

- Includes capital installation costs that determine adjustment dynamics over time
  - Capital stock levels do not adjust instantly or costlessly
  - Quadratic costs control how fast economy responds (Goulder, McKibbin/Wilcoxen)

EMPAX-CGE: Changes in Technology

- Baseline energy efficiency improvements from AEO energy consumption forecasts

- Model structure allows technology improvements (not a fixed coefficient input-output approach)

- Model structure captures effects from changes in energy prices

  - Encouragment of industry fuel efficiency through use of additional capital/labor in place of fuel

  - Substitution out of energy goods by households due to increase in energy prices

- All interactions between energy and economy are considered (e.g., lower energy consumption, use of additional capital in manufacturing, extra purchasing power of households)

EMPAX-CGE: Tax Interactions

- Includes distortions from taxes:
  - Labor (FICA) and sales/excise taxes – IMPLAN data
  - Personal income taxes – based on NBER TAXSIM data
  - Capital – user cost of capital formulation (e.g., Fullerton)

- Labor supply elasticities control willingness of households to switch between labor and leisure
  - Compensated elas of 0.4, uncompensated elas of 0.15 (based on Goulder, Williams, Fullerton, others)

- Estimates of baseline tax distortions in model:
  - MCPF – marginal cost of public funds (~1.22)
  - MEB – marginal excess burden (~0.31)

EMPAX-CGE: Households

- Need to examine how spillover effects of policies will affect labor and capital markets, thus altering purchasing power of households

- IMPLAN data define consumption patterns and income sources for 9 groups based on:
  - US BLS - *Consumer Expenditure Survey*
  - US Census Bureau - *Decennial Census & Population Survey*

EMPAX-CGE: Households

- To capture important effects, several households are specified in each region based on income

- Different groups are run simultaneously in model so that interactions between households' decisions and policies are determined endogenously by the model

- Typically aggregate households into
  4 types in each of 5 regions = 20 households
    - $0 to $14,999
    - $15,000 to $29,999
    - $30,000 to $49,999
    - $50,000 and above

EMPAX-CGE: Environmental Expenditures

- Environmental expenditures (e.g., compliance cost estimates from IPM and/or AirControlNet) must be allocated to purchases of inputs from other industries within CGE model

  - In absence of other data, Nestor and Pasurka (1995) information on environmental protection expenditures forms basis of this allocation

- Allows model to capture ripple effect to other sectors associated with environmental expenditures by linking them to purchases of their goods and services (and factors of production)

EMPAX-CGE: Outputs

- General: GDP, welfare (EV), trade, investment
- Production
  - Output by sector ($ and %)
  - Labor use by sector ($ and %)
  - Capital earnings by sector ($ and %)
- Households
  - Consumption of goods ($ and %)
  - Labor supply decisions
- Energy
  - Production by type ($ and BTU and %)
  - Industrial consumption by fuel ($ and BTU and %)
  - Household consumption by fuel ($ and BTU or kWh and %)
  - Heatrates in electricity generation (BTU per kWh)

EMPAX-CGE: External Peer Review

- ## Dr. Charles Ballard, Economics Professor, Michigan State University
  - In many ways, the model described there is an impressive piece of work… generally speaking, I believe that this model is capable of providing insights into the effects of environmental policy changes.

- ## Dr. Christoph Bohringer, Professor, Center for European Economic Research
  - Overall, the model documentation conveys the impression of solid competent work.

- ## Dr. Hillard Huntington, Stanford Energy Modeling Forum
  - The model will be very useful for deriving regional and sectoral impacts of environmental policies that use economic instruments that directly affect the costs of using different energy types.

- ## Suggestions for Improvement:
  - Provide results from analyses – at the time, there were no publicly available findings.
  - Conduct sensitivity analyses to illustrate model reactions.
  - Consider adjusting some of the elasticity parameters
  - Add additional descriptions of policy evaluation techniques.

EMPAX-CGE Output
## (CAIR: Energy Intensive Production - US)

Model Run	Industry	2005	2010	2015	2020	2025	Growth Rate / Average Effect
Baseline Revenue ($ million)	Food and Kindred	$428,137	$460,434	$494,433	$529,365	$563,832	1.4%
	Paper and Allied	$168,599	$186,194	$205,503	$221,028	$236,642	1.7%
	Chemicals	$437,013	$514,623	$593,712	$670,607	$747,446	2.7%
	Glass	$22,082	$26,330	$29,489	$32,245	$35,979	2.5%
	Cement	$6,829	$7,776	$8,571	$8,952	$9,270	1.5%
	Iron and Steel	$83,072	$94,430	$100,583	$101,146	$103,321	1.1%
	Aluminum	$41,747	$46,458	$50,889	$53,445	$56,737	1.5%
Scenario Revenue ($ million)	Food and Kindred	$428,048	$460,237	$494,181	$529,018	$563,478	1.4%
	Paper and Allied	$168,607	$186,125	$205,393	$220,861	$236,472	1.7%
	Chemicals	$436,961	$514,426	$593,398	$670,049	$746,859	2.7%
	Glass	$22,087	$26,318	$29,470	$32,214	$35,947	2.5%
	Cement	$6,827	$7,775	$8,568	$8,946	$9,264	1.5%
	Iron and Steel	$83,089	$94,396	$100,526	$101,056	$103,235	1.1%
	Aluminum	$41,770	$46,460	$50,878	$53,424	$56,713	1.5%
Difference in Revenue ($ million)	Food and Kindred	-$90	-$197	-$252	-$347	-$354	-$248
	Paper and Allied	$8	-$69	-$110	-$168	-$170	-$102
	Chemicals	-$51	-$197	-$314	-$558	-$588	-$341
	Glass	$5	-$12	-$19	-$31	-$32	-$18
	Cement	-$2	-$1	-$3	-$5	-$5	-$3
	Iron and Steel	$17	-$34	-$57	-$89	-$85	-$50
	Aluminum	$23	$1	-$11	-$22	-$24	-$6
Percentage Change in Revenue (%)	Food and Kindred	-0.02%	-0.04%	-0.05%	-0.07%	-0.06%	-0.05%
	Paper and Allied	0.00%	-0.04%	-0.05%	-0.08%	-0.07%	-0.05%
	Chemicals	-0.01%	-0.04%	-0.05%	-0.08%	-0.08%	-0.05%
	Glass	0.02%	-0.04%	-0.06%	-0.10%	-0.09%	-0.05%
	Cement	-0.03%	-0.02%	-0.03%	-0.06%	-0.05%	-0.04%
	Iron and Steel	0.02%	-0.04%	-0.06%	-0.09%	-0.08%	-0.05%
Percentage Change in Quantity (%)	Food and Kindred	-0.01%	-0.03%	-0.04%	-0.05%	-0.05%	-0.04%
	Paper and Allied	0.00%	-0.04%	-0.05%	-0.08%	-0.07%	-0.05%
	Chemicals	-0.02%	-0.04%	-0.05%	-0.08%	-0.08%	-0.05%
	Glass	0.00%	-0.06%	-0.08%	-0.12%	-0.12%	-0.08%
	Cement	0.06%	-0.04%	-0.07%	-0.09%	-0.09%	-0.05%
	Iron and Steel	0.05%	-0.04%	-0.07%	-0.10%	-0.10%	-0.05%
	Aluminum	-0.02%	-0.12%	-0.14%	-0.19%	-0.17%	-0.13%

EMPAX-CGE Output
(CAIR: Production Changes - US)

Percent Change from Baseline
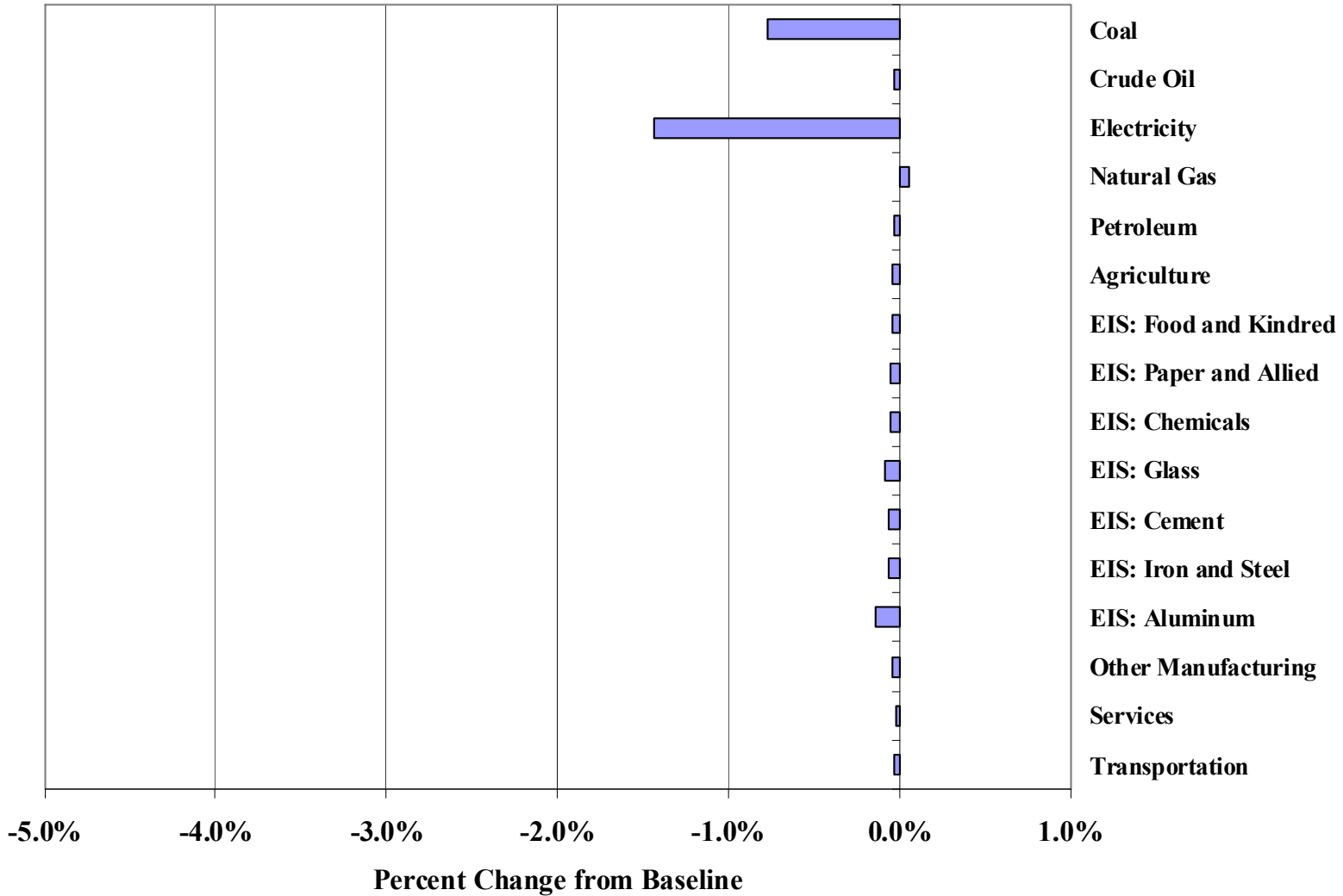
EMPAX-CGE Output
(CAIR: Regional Production Changes)

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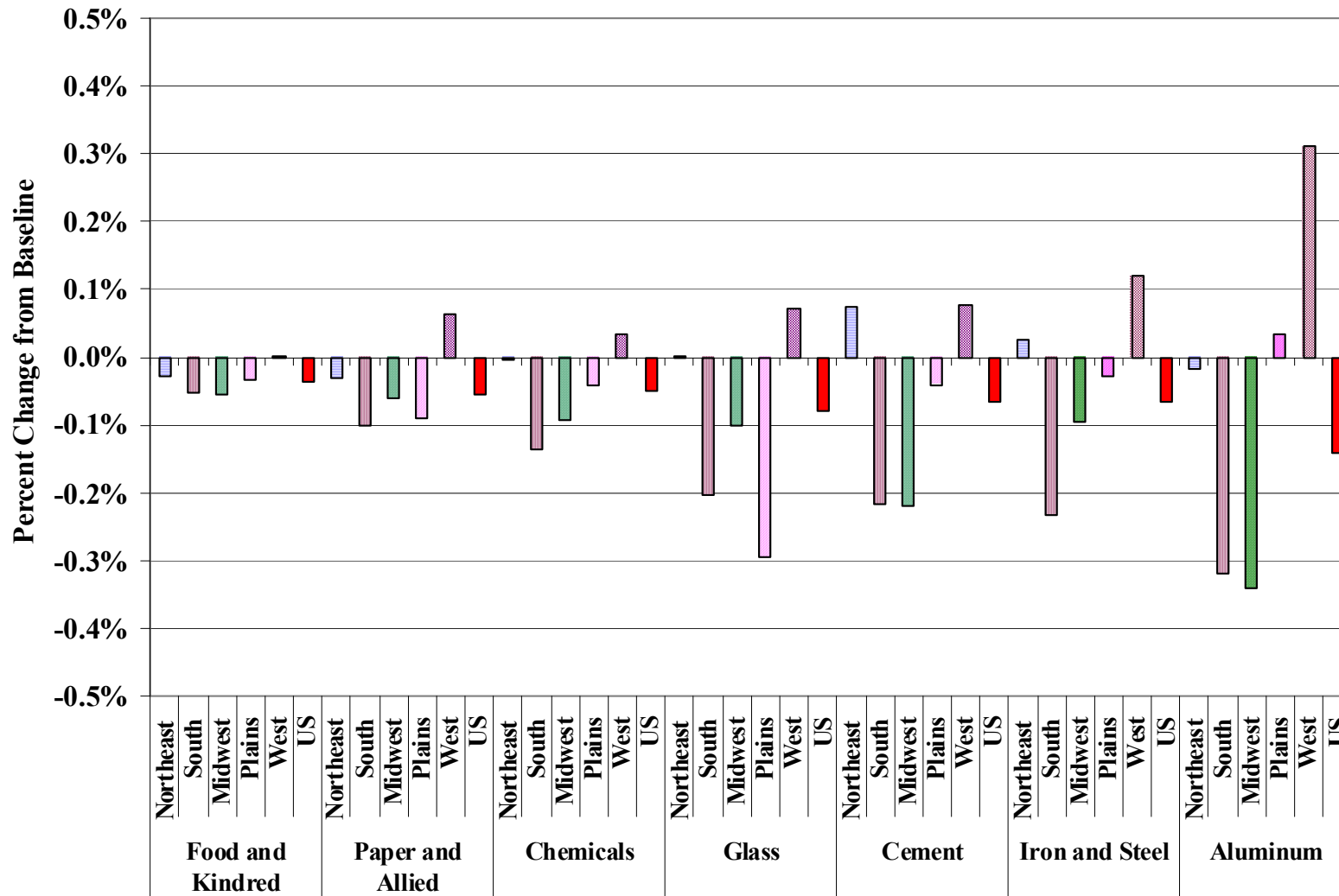
EMPAX-CGE: Extensions to Model

- General Updates

  - Use 2004 state economic data that RTI got from IMPLAN

    - current version uses 2000 IMPLAN data

  - Newer AEO forecasts (2006 or 2007)

    - current version uses AEO 2003

- Additional Industries

  - Increase the number of industries from current 17 to perhaps 25-30, depending on model willingness (tradeoff between industry coverage v. computing efficiency) – many nonlinear equations in dynamic EMPAX version makes convengence concerns important

Possible Additional Industries for Inclusion in EMPAX-CGE

- Mining – NAICS 21 (mining other than coal)
- Construction – NAICS 23
- Services
  - Wholesale & Retail Trade (NAICS 42, 44-45)
  - Transportation Services (NAICS 48)
  - Information (NAICS 51)
  - Business/Professional (NAICS 52-56)
  - Education (NAICS 61)
  - Health Care (NAICS 62)
  - Other Services (NAICS 71, 72, 81)
  - Public Services (NAICS 92)

EMPAX-CGE: Extensions to Model

- Developing a state-level version of EMPAX; to do so,

- Run a regional model of the U.S.
(use current 5 regions)

- Pass relevant results to individual state model (under development)

- State-level version of EMPAX then uses regional/U.S. impacts to estimate state-specific effects of a policy – useful for driving emission projection models (e.g. EGAS)

- Difficulties:
  - Getting model baselines to solve is significant effort
    (especially with more industries and regions)
  - How to make the model framework flexible:
    - save new policy results into model baselines
    - possible shifts in industries or time frame?

EMPAX-CGE: Extensions to Model

- Global Insights forecasts of economic activity
  - Annual forecasts for around 25 years into future to help guide the baseline solution in EMPAX
  - Most important forecasts are for:
    - Real state GSP by NAICS (generally 2-digit)
    - Industrial production indices for manufacturing (3-digit NAICS)
  - Other possible data includes things like number of households, employment, income, etc.
- Use EMPAX baseline to provide information to EGAS model (for emissions growth) on things like industrial output and earnings, income, consumption, fuel use
- EMPAX should be updated to include changes listed above in first half of 2008

Need more information?

- Model documentation is on the Internet at http://www.epa.gov/ttn/ecas/EMPAXCGE.htm In addition, responses to peer review questions are also found at this web site

- Or, contact Larry Sorrels (sorrels.larry@epa.gov) or Tom Walton (walton.tom@epa.gov) for more information