April 2010

812 Economic Analyses Using the EMPAX-CGE Modeling System

Revised Draft Report

Prepared for

ICF Incorporated LLC
9300 Lee Highway
Fairfax, VA 22031

Prepared by

RTI International
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RTI International is a trade name of Research Triangle Institute.

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SECTION 1
EMPAX COMPUTABLE GENERAL EQUILIBRIUM (CGE) MODEL

EMPAX was first developed in 2000 to support economic analysis of the U.S. Environmental Protection Agency's (EPA's) maximum achievable control technology (MACT) rules for combustion sources (reciprocating internal combustion engines, boilers, and turbines). The initial framework consisted of a national multimarket partial-equilibrium model with linkages only between manufacturing industries and the energy sector. Modified versions of EMPAX were subsequently used to analyze economic impacts of strategies for improving air quality in the Southern Appalachian mountain region as part of efforts associated with the Southern Appalachian Mountain Initiative (SAMI). Later work extended its scope to cover all aspects of the U.S. economy with regional detail.

Since large-scale environmental policies also indirectly influence current and future input uses, income, and household consumption patterns, EPA subsequently updated the model to include a complete set of economic linkages among all industrial and energy sectors as well as households that supply factors of production such as labor and purchase goods (i.e., a computable general equilibrium [CGE] framework). As a result, EMPAX is now a dynamic general equilibrium model that traces economic impacts as they are transmitted across time and throughout the economy. EMPAX-CGE underwent peer review in 2006; detailed model documentation and results of the peer review can be accessed at the following Web site: http://www.epa.gov/ttnecas1/EMPAXCGE.htm.

1.1 Model Structure

EMPAX-CGE is a dynamic, intertemporally optimizing model that solves in 5-year intervals from 2005 to 2050. It uses the classical Arrow- Debreu general equilibrium framework wherein households maximize utility subject to budget constraints, and firms maximize profits subject to technology constraints. The model structure, in which agents are assumed to have perfect foresight and maximize utility across all time periods, allows agents to modify behavior in anticipation of future policy changes, unlike dynamic recursive models that assume agents do not react until a policy has been implemented.

Nested CES functions are used to portray substitution possibilities available to producers and consumers. Figure 1-1 illustrates this general framework and gives a broad characterization

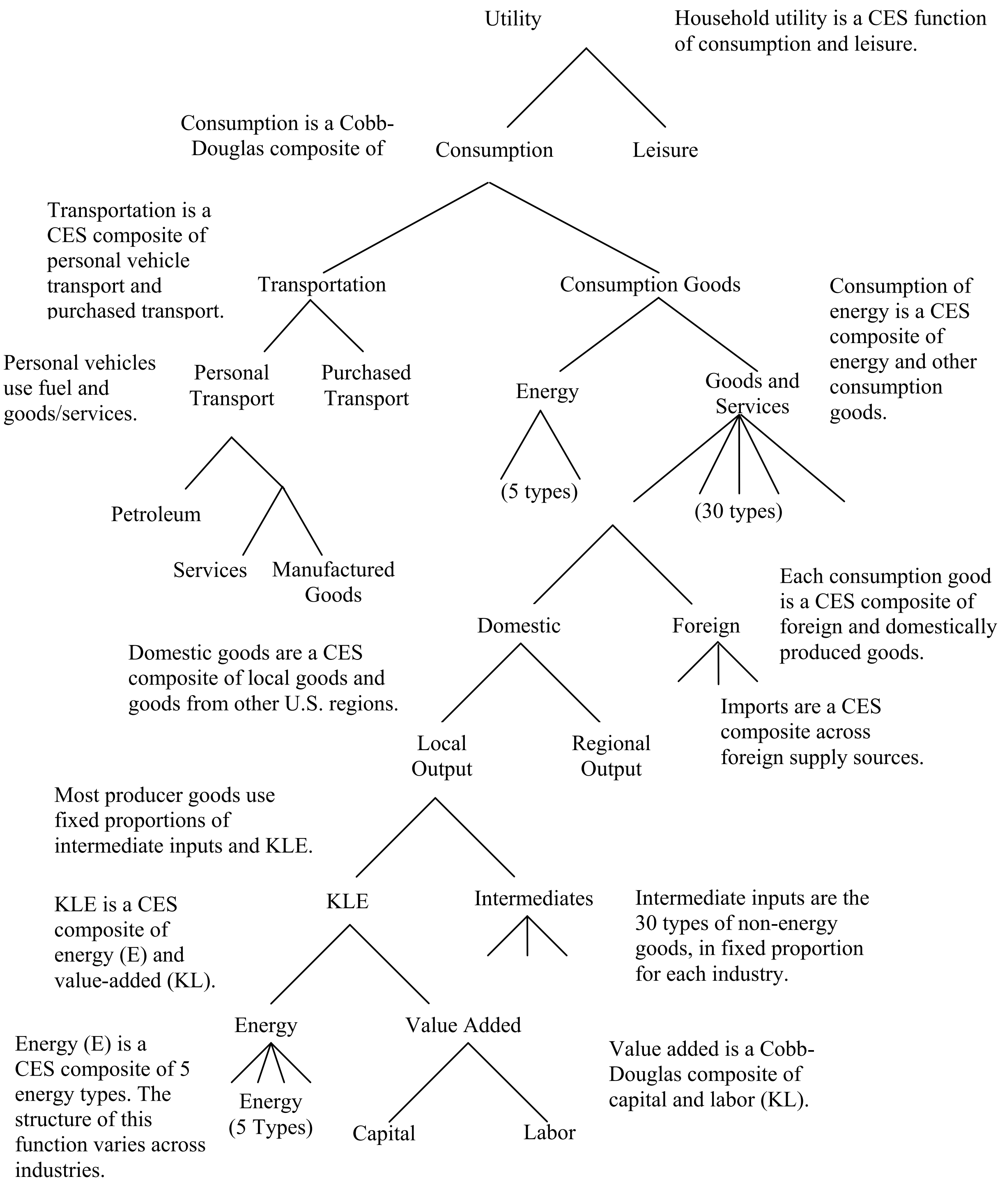

Figure 1-1. General Production and Consumption Nesting Structure in EMPAX-CGE

of the model.[1] Along with the underlying data, these nesting structures and associated substitution elasticities determine the effects that will be estimated for policies. These nesting structures and elasticities used in EMPAX-CGE are generally based on the Emissions Prediction and Policy Analysis (EPPA) Model developed at the Massachusetts Institute of Technology (MIT) (Paltsev et al., 2005). This updated version of the EPPA model incorporates some extensions over the EPPA version documented in Babiker et al. (2001) such as specification of transportation purchases by households. These updates to transportation choices have been incorporated in this version of EMPAX-CGE as shown on the left-hand side of Figure 1-1. Although the two models continue to have different focuses (EPPA is a recursive dynamic, international model focused on national-level climate change policies), both are intended to simulate how agents will respond to environmental policies and as such EPPA provides a strong basis to develop the theoretical structure of EMPAX-CGE.

Given this basic similarity, EMPAX-CGE has adopted a comparable structure. EMPAX-CGE is programmed in the GAMS[2] language (Generalized Algebraic Modeling System) and solved as a mixed complementarity problem (MCP)[3] using MPSGE software (Mathematical Programming Subsystem for General Equilibrium).[4] The PATH solver from GAMS is used to solve the MCP equations generated by MPSGE.

1.1.1 Data Sources

The economic data come from state-level information provided by the Minnesota IMPLAN Group[5] and energy data come from the Energy Information Administration (EIA).[6] Forecasts for economic growth are taken from EIA's *Annual Energy Outlook 2007* (AEO) and Global Insight.[7] Although IMPLAN data contain information on the value of energy production and consumption in dollars, these data are replaced with EIA data since the policies being investigated by EMPAX-CGE typically focus on energy markets, making it essential to include

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[1] Although it is not illustrated in Figure 1-1, some differences across industries exist in their handling of energy inputs. In addition, the agriculture and fossil-fuel sectors in EMPAX-CGE contain equations that account for the presence of fixed inputs to production (land and fossil-fuel resources, respectively).

[2] See Brooke, Kendrick, and Meeraus (1996) for a description of GAMS (http://www.gams.com/).

[3] Solving EMPAX-CGE as a MCP problem implies that complementary slackness is a feature of the equilibrium solution. In other words, any firm in operation will earn zero economic profits and any unprofitable firms will cease operations. Similarly, for any commodity with a positive price, supply will equal demand, or conversely any good in excess supply will have a zero price.

[4] See Rutherford (1999) for MPSGE documentation (http://www.mpsge.org/).

[5] See http://www.implan.com/index.html for a description of the Minnesota IMPLAN Group and its data.

[6] These EIA sources include *AEO 2007*, the *Manufacturing Energy Consumption Survey*, *State Energy Data Report*, *State Energy Price and Expenditure Report*, and various annual industry profiles.

[7] See http://www.globalinsight.com/ProductsServices/ProductDetail1100.htm for a description of the Global Insight U.S. State Forecasting Service.

the best possible characterization of these markets in the model. Although the IMPLAN data are developed from a variety of government data sources at the U.S. Bureau of Economic Analysis and U.S. Bureau of Labor Statistics, these data do not always agree with energy information collected by EIA directly from manufacturers and electric utilities.

EMPAX-CGE combines these economic and energy data to create a balanced social accounting matrix (SAM) that provides a baseline characterization of the economy. The SAM contains data on the value of output in each sector, payments for factors of production and intermediate inputs by each sector, household income and consumption, government purchases, investment, and trade flows. A balanced SAM for the year 2005 consistent with the desired sectoral and regional aggregation is produced using procedures developed by Babiker and Rutherford (1997) and described in Rutherford and Paltsev (2000). This methodology relies on optimization techniques to maintain the calculated energy statistics (in both quantity and value terms) while minimizing any changes needed in the other economic data to create a new balanced SAM based on EIA/IMPLAN data for the baseline model year (in essence, industry production functions are adjusted, if necessary, to account for discrepancies between EIA energy data and IMPLAN economic data by matching the energy data and adjusting the use of nonenergy inputs so that the industry is in balance, that is, the value of inputs to production equals the value of output).

These data are used to define economic conditions in 50 states within the United States (plus the District of Columbia), each of which contains 80 industries. Prior to solving EMPAX-CGE, the states and industries are aggregated up to the categories to be included in the analysis. Aggregated regions have been selected to capture important differences across the country in electricity generation technologies, while industry aggregations are controlled by available energy consumption data.

Table1-1 presents the 35 industry categories included in EMPAX-CGE for policy analysis. Their focus is on maintaining as much detail in the energy-intensive and manufacturing sectors[8] as is allowed by available energy consumption data and computational limits of dynamic CGE models. In addition, the electricity industry is separated into fossil fuel generation and nonfossil generation, which is necessary because many electricity policies affect only fossil fuel-fired electricity.

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[8] Energy-intensive industry categories are based on EIA definitions of energy-intensive manufacturers in the *Assumptions for the Annual Energy Outlook 2007*.

Table 1-1. Industries in Dynamic EMPAX-CGE

EMPAX Industry	North American Industry Classification System (NAICS)
Energy	
Coal	2121
Crude oil[a]	211111, 4861
Electricity (*fossil*)	2211
Electricity (*nonfossil*)	2211
Natural gas	211112, 2212, 4862
Petroleum refining [c]	324, 48691
General	
Agriculture	11
Mining (w/o coal, crude, gas)	21
Construction	23
Manufacturing	
Food products	311
Textiles and apparel	313, 314, 315, 316
Lumber	321
Paper and allied	322
Printing	323
Chemicals	325
Plastic and rubber	326
Glass	3272
Cement	3273
Other minerals	3271, 3274, 3279
Iron and steel	3311, 3312
Aluminum	3313
Other primary metals	3314, 3316
Fabricated metal products	332
Manufacturing equipment	333
Computers & communication equipment	334
Electronic equipment	335
Transportation equipment	336
Miscellaneous remaining	312, 337, 339
Services	
Wholesale & retail trade	42, 44, 45
Transportation [b]	481-488
Information	51
Finance and real estate	52, 54
Business/professional	53, 55, 56
Education (w/public)	61
Health care (w/public)	62
Other services	71, 72, 81, 92

[a] Although NAICS 211111 covers crude oil and gas extraction, the gas component is moved to the gas industry.

[b] The petroleum refining industry provided oil in delivered terms, which includes pipeline transport.

[c] Transportation does not include NAICS 4862 (natural gas distribution), which is part of the natural gas industry.

Figure 1-2 shows the five regions run in EMPAX-CGE in this analysis, which have been defined based on the expected regional distribution of policy impacts, availability of economic and energy data, and computational limits on model size. These regions have been constructed from the underlying state-level database designed to follow, as closely as possible, the electricity market regions defined by the North American Electric Reliability Council (NERC).[9]

Figure 1-2. Regions Defined in Dynamic EMPAX-CGE

1.1.2 Production Functions

All productive markets are assumed to be perfectly competitive and have production technologies that exhibit constant returns to scale, except for the agriculture and natural resource extracting sectors, which have decreasing returns to scale because they use factors in fixed supply (land and fossil fuels, respectively). The electricity industry is separated into two distinct sectors: fossil fuel generation and nonfossil generation. This allows tracking of variables such as heat rates for fossil fired utilities (BTUs of energy input per kilowatt hour of electricity output).

All markets must clear (i.e., supply must equal demand in every sector) in every period, and the income of each agent in the model must equal their factor endowments plus any net transfers. Along with the underlying data, the nesting structures shown in Figure 1-1 and

[9] Economic data and information on nonelectricity energy markets are generally available only at the state level, which necessitates an approximation of the NERC regions that follows state boundaries.

associated substitution elasticities define current production technologies and possible alternatives.

1.1.3 Utility Functions

Each region in the dynamic version of EMPAX-CGE contains four representative households, classified by income, that maximize intertemporal utility over all time periods in the model subject to budget constraints, where the income groups are:

- $0 to $14,999,
- $15,000 to $29,999,
- $30,000 to $49,999, and
- $50,000 and above.

These representative households are endowed with factors of production including labor, capital, natural resources, and land inputs to agricultural production. Factor prices are equal to the marginal revenue received by firms from employing an additional unit of labor or capital. The value of factors owned by each representative household depends on factor use implied by production within each region. Income from sales of these productive factors is allocated to purchases of consumption goods to maximize welfare.

Within each time period, intratemporal utility received by a household is formed from consumption of goods and leisure. All consumption goods are combined using a Cobb-Douglas structure to form an aggregate consumption good. This composite good is then combined with leisure time to produce household utility. The elasticity of substitution between consumption goods and leisure depends on empirical estimates of labor supply elasticities and indicates how willing households are to trade off leisure time for consumption. Over time, households consider the discounted present value of utility received from all periods’ consumption of goods and leisure.

Following standard conventions of CGE models, factors of production are assumed to be mobile among sectors within regions, but migration of productive factors is not allowed across regions. This assumption is necessary to calculate welfare changes for the representative household located in each region in EMPAX-CGE. EMPAX-CGE also assumes that ownership of natural resources and capital embodied in nonfossil electricity generation is spread across the United States through capital markets.

1.1.3.1 Welfare Measures

To analyze the social benefits and costs of policy alternatives, EMPAX uses a willingness-to-pay measure known as Hicksian *equivalent variation* (EV). EV reflects the additional money that a household would need (at original prices p^0 and income m^0) to make it *as well off* with the new policy; the amount is money "equivalent" to the changes in the utility households receive from consumption and leisure time.

$$EV = u(p^0; p', m') - u(p^0; p^0, m^0) = u(p^0; p', m') - m^0$$

where

p^0 = the baseline prices,

m^0 = baseline income,

p' = with policy prices, and

m' = with policy income.

The EMPAX-CGE modeling system has traditionally estimated the social cost of environmental regulation. Environmental benefits of air quality improvements have not to date been considered within the modeling system. In this analysis, EPA has considered a subset of environmental benefit adjustments within the modeling system and continues to provide an EV welfare metric associated with consumption and leisure However, the welfare metric still excludes other direct "willingness to pay" (WTP) welfare effects that are included in the 812 benefits analysis.

1.1.4 Trade

In EMPAX-CGE, all goods and services are assumed to be composite, differentiated "Armington" goods made up of locally manufactured commodities and imported goods. Output of local industries is initially separated into output destined for local consumption by producers or households and output destined for export. This local output is then combined with goods from other regions in the United States using Armington trade elasticities that indicate agents make relatively little distinction between output from firms located within their region and output from firms in other regions within the United States. Finally, the domestic composite goods are aggregated with imports from foreign sources using lower trade elasticities to capture the fact that foreign imports are more differentiated from domestic output than are imports from other regional suppliers in the United States.

1.1.5 Tax Rates and Distortions

Taxes and associated distortions in economic behavior have been included in EMPAX-CGE because theoretical and empirical literature found that taxes can substantially alter estimated policy costs (e.g., Bovenberg and Goulder [1996]; Goulder and Williams [2003]). For example, existing labor taxes distort economic choices because they encourage people to work below the levels they would choose in an economy without labor taxes; as a result labor taxes reduce economic efficiency[10]. When environmental policies raise firms' production costs and the prices of goods and services, real wages fall, and people may choose to work less. When people choose to work less, the pre-existing tax distortion is made worse and the additional economic costs have been described as the "tax interaction" effect.

EMPAX-CGE considers these interaction effects by using tax data from several sources and by explicitly modeling household labor supply decisions. The IMPLAN economic database provides information on taxes such as indirect business taxes (all sales and excise taxes) and social security taxes. However, since IMPLAN reports factor payments for labor and capital at their gross of tax values, we use additional data sources to determine personal income and capital tax rates. Information from the TAXSIM model at the National Bureau of Economic Research (Feenberg and Coutts, 1993), along with user cost-of-capital calculations from Fullerton and Rogers (1993), are used to establish tax rates. Elasticity parameters describing labor supply choice ultimately determine how distortionary existing taxes are in the CGE model. EMPAX-CGE currently uses elasticities based on the relevant literature (i.e., 0.4 for the compensated labor supply elasticity and 0.15 for the uncompensated labor supply elasticity). These elasticity values give an overall marginal excess burden associated with the existing tax structure of approximately 0.3.

1.1.6 Intertemporal Dynamics and Economic Growth

EMPAX-CGE includes four sources of economic growth: technological change from improvements in energy efficiency, growth in the available labor supply (from both population growth and changes in labor productivity), increases in stocks of natural resources, and capital accumulation. Energy consumption per unit of output tends to decline over time because of improvements in production technologies and energy conservation. These changes in energy use per unit of output are modeled as Autonomous Energy Efficiency Improvements (AEEI), which

[10] These efficiency losses are often expressed in terms of overall marginal excess burden; the cost associated with raising an additional dollar of tax revenue. Estimates range from \$0.10 to \$0.35 per dollar (Ballard et al, 1985).

are used to replicate energy consumption forecasts by industry and fuel from EIA.[11] The AEEI values provide the means for matching expected trends in energy consumption that have been taken from the AEO forecasts. They alter the amount of energy needed to produce a given quantity of output by incorporating improvements in energy efficiency and conservation. Labor force and regional economic growth, electricity generation, changes in available natural resources, and resource prices are also based on the AEO forecasts.

Savings provide the basis for capital formation and are motivated through people's expectations about future needs for capital. Savings and investment decisions made by households determine aggregate capital stocks in EMPAX-CGE. The IMPLAN data set provides details on the types of goods and services used to produce the investment goods underlying each region's capital stocks. Adjustment dynamics associated with formation of capital are controlled by using quadratic adjustment costs experienced when installing new capital, which imply that real costs are experienced to build and install new capital equipment.

Prior to investigating policy scenarios, it is necessary to establish a baseline path for the economy that incorporates economic growth and technology changes that are expected to occur in the absence of the policy actions. Beginning from the initial balanced SAM data set, the model is calibrated to replicate forecasts from the AEO 2007. Upon incorporating these forecasts, EMPAX-CGE is solved to generate a baseline based on them through 2030. Once this baseline is established, it is possible to run the "counterfactual" policy experiments discussed below.

1.1.7 Qualifications

Caveats that can typically be applied to CGE analyses, including this one, cover issues such as transitional dynamics in the economy. CGE models such as EMPAX, which assume foresight on the part of businesses and households, will allow agents to adapt to anticipated policy impacts coming in the future. These adaptations may occur more quickly than if agents adopted a wait-and-see approach to new regulations. The alternative, recursive-dynamic structure used in CGE models such as MIT's EPPA imply that no anticipation or adjustments will occur until the policy is in place, which tends to overstate the costs of policies.

In addition to transition dynamics, although CGE models are ideally suited for analyzing broad, economy-wide impacts of policies, they are not able to examine firm-specific impacts on profits/losses or estimate how policies may affect particular types of disadvantaged households.

[11] See Babiker et al. (2001) for a discussion of how this methodology was used in the EPPA model (EPPA assumes that AEEI parameters are the same across all industries in a country, while AEEI values in EMPAX-CGE are industry specific).

Similarly, environmental justice and other distributional concerns cannot be addressed adequately.

As noted above, the labor supply elasticities in the model have been chosen from the CGE literature on labor markets and tax distortions as discussed above. Other important assumptions about the production technologies and input substitution possibilities have been chosen from the MIT EPPA model. To ensure transparency of the assumptions, EMPAX-CGE underwent peer review in 2006, and detailed model documentation and results of the peer review can be accessed at the following Web site: http://www.epa.gov/ttnecas1/EMPAXCGE.htm.

1.1.8 Overview of the Analysis

The EMPAX-CGE model simulates and compares two potential macroeconomic outcomes: a U.S. economy with Clean Air Act programs and the U.S. economy without these programs. We use two methodological approaches that represent the Clean Air Act scenarios. The first approach only considers private compliance expenditures associated with Clean Air Act programs. The second includes private compliance expenditures and two benefits-related adjustments: (1) increases in the labor force associated with reduced mortality and morbidity and (2) household health expenditure reductions associated with improved health. We briefly present the data inputs for each approach below. Additional details describing how the data are produced are described in US EPA (2010).

1.1.8.1 Private Compliance Expenditures

Businesses and households make compliance expenditures to meet the Clean Air Act Program requirements; EPA estimates of the dollar value of these expenditures are reported in Table 1-2. Business compliance expenditures are distributed into purchases of environmental protection goods and services according to the expenditure shares computed in Nestor and Pasurka (1995). Within the EMPAX modeling system, changes are made to the productivity of inputs, requiring firms to use more of the specified inputs per unit of output. Similarly, the household utility function is adjusted to require additional expenditures on transportation services, manufactured goods, and petroleum products to achieve a given level of utility. Additional household compliance costs are transferred away from consumers in lump-sum fashion.[12]

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[12] Because of the foresight assumption in EMPAX, EPA compliance costs and benefits estimates must be extrapolated over the entire model time horizon (e.g., beyond 2020). This is accomplished by extending the 2020 costs and health expenditures by the growth in population. Percentage changes in the labor force are held constant at 2020 levels for periods beyond 2020.

Table 1-2. Estimated Private Compliance Expenditures with Clean Air Act Programs (billion, 2006$)

	2010		2020	
	Businesses	**Households**	**Businesses**	**Households**
West	$4	$7	$6	$11
Plains	$4	$4	$5	$4
Midwest	$8	$4	$10	$3
Southeast	$5	$4	$8	$4
Northeast	$9	$6	$10	$6
Total	$30	$25	$39	$30

Source: E.H. Pechan & Associates, Inc. and Industrial Economics, Inc. (2009)

1.1.7.1 Benefits Adjustments

The EMPAX-CGE modeling system can adjust the U.S. economy labor endowment due to air pollution-induced morbidity and mortality. To incorporate endowment changes, EPA assumed pollution-related illness and mortality proportionally reduce the representative households' time endowment (labor and leisure). Labor endowment adjustments used in the model are presented in Table 1-3.[13] EPA recognizes that the macroeconomic effects of labor time are complex and are likely to vary between workers and nonworkers. However, given the uncertainty and difficulties of incorporating changes in nonworker time within a general equilibrium framework, EPA did not attempt to quantify nonworker effects. As a result, the benefits adjusted model runs likely underestimate air quality benefits.

Table 1-3. Estimated Household Labor Endowment Increases with Clean Air Act Programs

	% Change		
EMPAX Region	**2010**	**2015**	**2020**
West	0.29%	0.43%	0.55%
Plains	0.19%	0.26%	0.32%
Midwest	0.48%	0.63%	0.74%
Southeast	0.32%	0.44%	0.54%
Northeast	0.40%	0.55%	0.65%
National	0.34%	0.47%	0.57%

Source: US EPA (2010)

[13] Details can be found in Chapter 8 of US EPA, 2010.

With Clean Air Act Programs, medical expenditures are typically lower because people are healthier; this frees up more household economic resources to use for other consumption and savings, and these choices influence the broader economy. To reflect this effect, the EMPAX-CGE modeling system adjusted pollution-related medical health expenditures as reported in Table 1-4.[14]

Table 1-4. Estimated Medical Savings with Clean Air Act Programs (billion, 2006$)

	Total Medical Expenditures		
EMPAX Region	**2010**	**2015**	**2020**
West	$2	$4	$4
Plains	$1	$1	$2
Midwest	$4	$5	$5
Southeast	$3	$4	$4
Northeast	$4	$5	$5
Total	$13	$18	$21

Source: US EPA (2010)

[14] Details can be found in Chapter 8 of US EPA, 2010.

SECTION 2
EMPAX-CGE MODEL RESULTS

We present EMPAX-CGE modeling system results for two different methodological approaches. The first only considers private compliance expenditures associated with Clean Air Act programs. The second includes private compliance expenditures and two benefits-related adjustments: (1) increases in the labor force associated with reduced mortality and morbidity and (2) household health expenditure reductions associated with improved health. National macroeconomic, welfare, and industry-specific output changes are reported and discussed below.

2.1 Private Compliance Expenditures Only

2.1.1 Macroeconomic Variables and Household Welfare Changes

The Clean Air Act programs' private compliance expenditures bring about changes in business and household behavior and will influence macroeconomic variables (gross domestic product [GDP] and consumption) and household economic welfare (Table 2-1 and Figure 2-1). Businesses and consumers will anticipate the regulation and attempt to smooth their response to the compliance expenditures over the entire model horizon. Each variable changes over time, and the percentage changes remain relatively constant.

Table 2-1. Macroeconomic and Welfare Variables Compared to Baseline without the Clean Air Act Amendments: Private Compliance Expenditures Only (2010 to 2030)

Macroeconomic Summary				
Variable	**Model Run**	**2010**	**2015**	**2020**
GDP	With Clean Air Act (billion)	$15,027	$17,338	$20,202
	Without Clean Air Act (billion)	$15,106	$17,429	$20,310
	Change (billion)	−$78	−$91	−$108
	% change	−0.52%	−0.52%	−0.53%
Consumption	With Clean Air Act (billion)	$10,969	$12,699	$14,881
	Without Clean Air Act (billion)	$11,026	$12,765	$14,961
	Change (billion)	−$58	−$66	−$79
	% change	−0.52%	−0.52%	−0.53%
Hicksian EV (annual)	Change (billion)	−$59	−$68	−$82
	% change	−0.41%	−0.41%	−0.42%
Hicksian EV (PV of infinite horizon)	Change (billion)	−$2,206		
	% change	−0.40%		

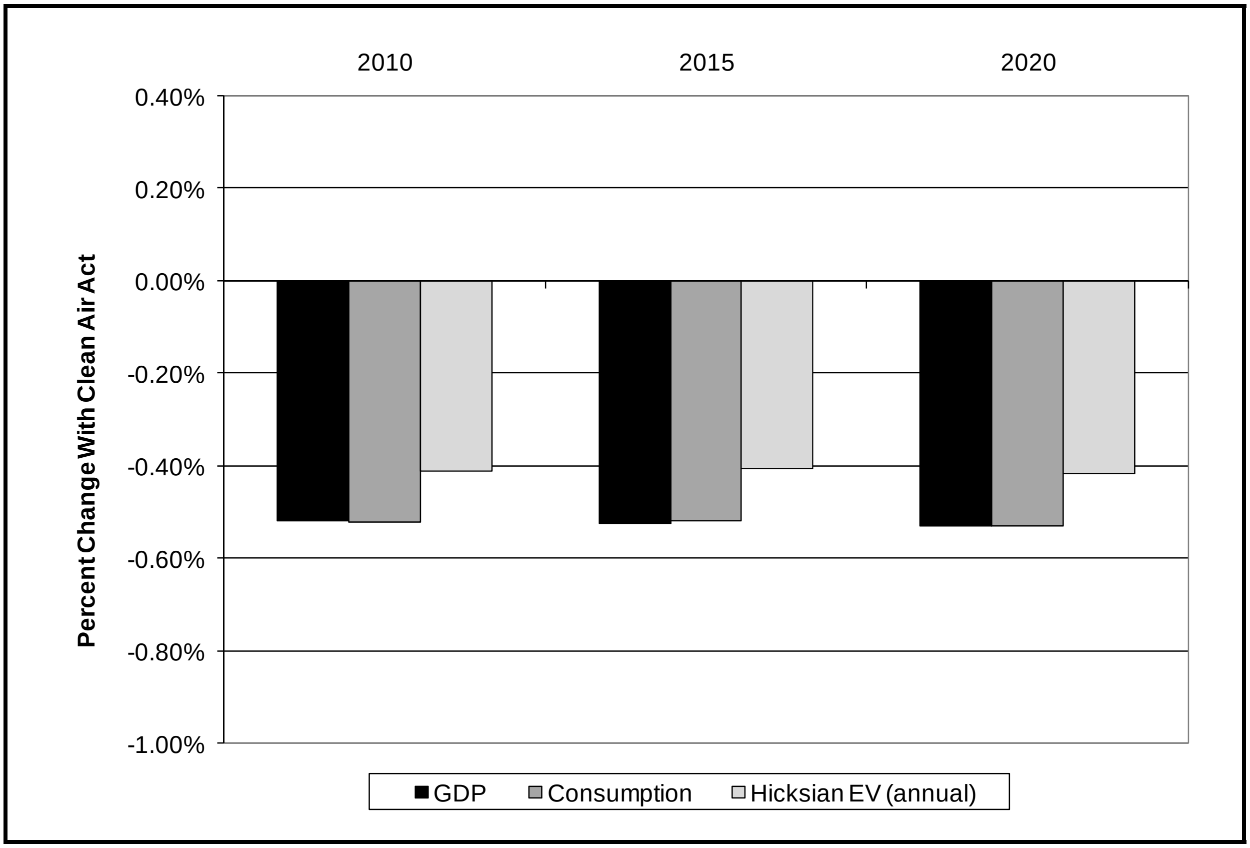

Figure 2-1. Macroeconomic and Welfare Variables Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Private Compliance Expenditures Only (2010 to 2030)

For each model year (2010, 2015, and 2020), U.S. GDP is approximately 0.5% lower with the Clean Air Act programs. In 2020, the projected GDP decrease is equivalent to a $108 billion. Consumption is also 0.5% lower with Clean Air Act programs. In 2020, consumption falls by $79 billion.

Average annual welfare levels (as measured by Hicksian equivalent variation) are approximately 0.4% lower with Clean Air Act programs. However, in this approach, the EMPAX modeling system does not incorporate any environmental benefits associated with air quality improvements. As a result, EMPAX welfare measures only approximate the Clean Air Act programs' social cost. The total present value of these losses over the infinite horizon is approximately $2.2 trillion.[15] In 2020, the annual social costs are estimated to be approximately

[15] Values are discounted back to 2005 at the 5% interest rate used in the model.

$39 billion. Since the EV calculation accounts for benefits associated with additional leisure time, the decline in EV is smaller than the change in GDP.

2.1.2 Industry-Level Effects

The first order effects of Clean Air Act programs involve output reductions associated with the higher costs of making goods and services. Relative changes in output effects are typically higher for industries having private costs that are high relative to the industry size (Figure 2-2). For example, the electricity industry accounts for approximately 20% of the Clean Air Act program costs (~$14 billion, or 3.3% of benchmark electricity revenue); as a result, the general equilibrium model suggests that electricity output levels are nearly 4% lower relative to a U.S. economy without Clean Air Act programs. Electricity output reductions also have an important secondary effect because of the reduced needs for coal; coal output levels drop by 1.5%. In addition, electricity prices increases lead energy-dependent sectors that rely on electricity to switch to other energy sources (e.g., natural gas and oil) and/or seek energy efficiency improvements in their production process. Petroleum production also tends to benefit from substitution effects as other energy sources become relatively more expensive More importantly, households will be required to purchase cleaner (more expensive) fuels. As a result, petroleum sector output increases to meet the demand for higher quality petroleum products.

Furthermore, important secondary effects are associated with private cost expenditures required to meet Clean Air Act goals. Within EMPAX-CGE, each dollar spent to comply with Clean Air Act programs is used to buy environmental protection goods and services.[16] In addition, household private costs require them to spend additional dollars on transportation goods and services (oil, manufacturing goods such as engines, and inspection and maintenance services). As a result, the demand for environmental protection goods and services will be higher relative to a U.S. economy without Clean Air Act programs. This secondary effect can diminish some of the output losses in sectors that incur compliance costs and provide environmental protection goods and services. In some instances, such as the petroleum sector, the combined effects of energy substitution and demand increases for environmental protection goods/services completely offset any output losses and lead to small output increases.

The service sectors are relatively unaffected by the Clean Air Act programs, with the exception of the transportation services industry. The non-transportation service sectors do not

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[16] Details are described in EMPAX-CGE model documentation (5-2 to 5-5). In addition, household private costs require them to spend additional dollars on transportation goods and services (oil, manufacturing goods such as engines, and inspection and maintenance services).

incur significant costs, so output changes are small. In addition, other industries and households will spend some of their compliance expenditures on services (e.g. finance and real estate).

The transportation services sector experiences a larger decline than the other service sectors because it bears high private compliance costs, relative to the size of the industry. The transportation services sector is also more energy intensive than other service industries and production costs are indirectly affected by higher energy prices (oil is an important production input). The negative effects of private compliance costs and higher energy prices are partially offset by the increased demand for transportation services by households under the Clean Air Act.

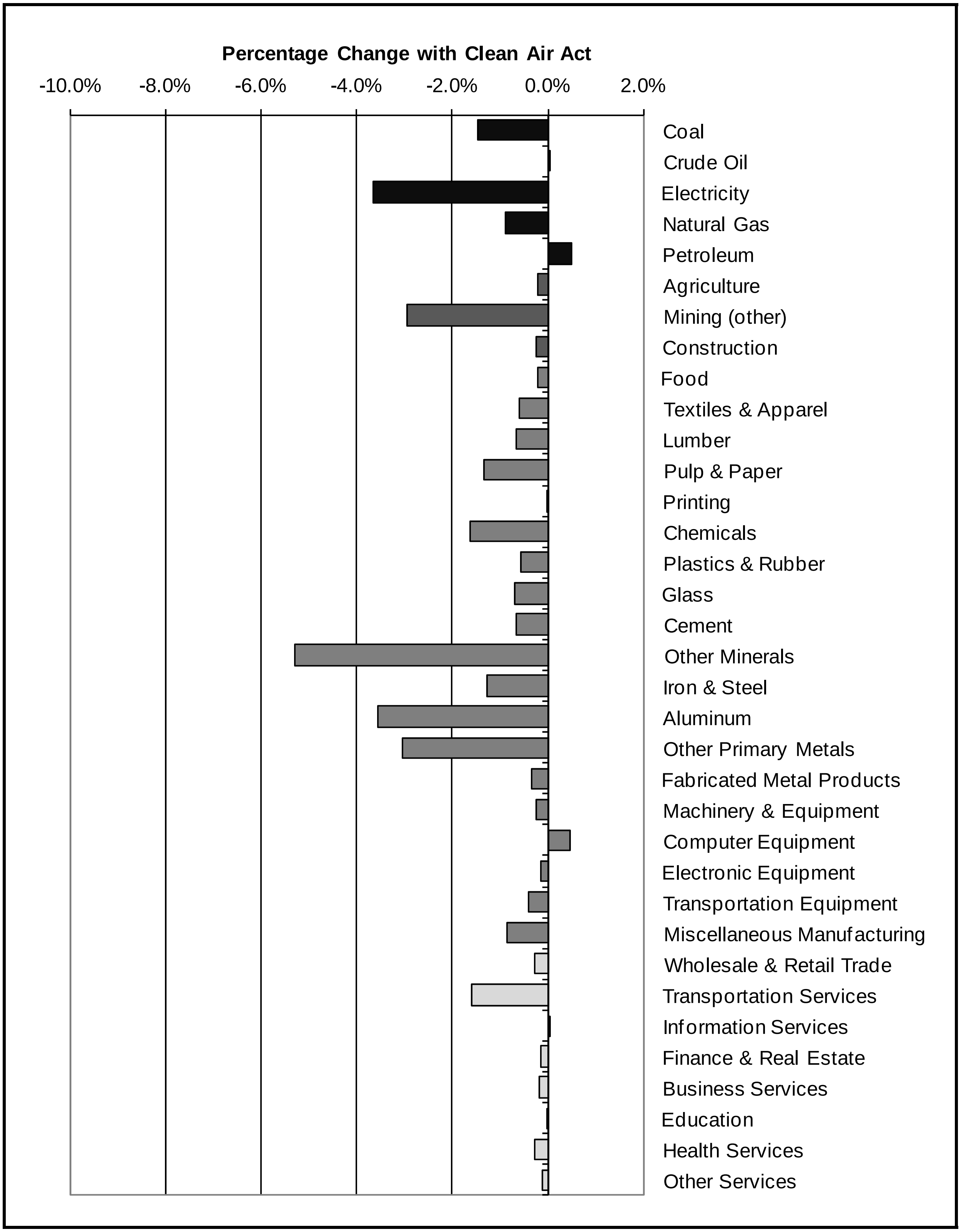

Figure 2-2. National Industry Output Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Private Compliance Expenditures Only (2020)

2.2 Air Quality Benefits Adjustments and Private Compliance Expenditures

2.2.1 Macroeconomic Variables and Household Welfare Changes

Under the second approach, the EMPAX-CGE modeling system estimate macro variable changes that also include behavior responses brought about by selected air quality benefits (Table 2-2 and Figure 2-3). These benefits offset some of the private expenditures, and the net effects tend to be slightly higher than a baseline without Clean Air Act programs. For example, after 2015, GDP increases as more people experience fewer lost working days and health expenditures also fall. In 2020, the projected GDP increases by $18 billion, or 0.09%. Consumption is also higher with Clean Air Act programs after 2015. In 2020, consumption rises by $8 billion, 0.06% for the year 2020.

Table 2-1. Macroeconomic and Welfare Variables Compared to Baseline without the Clean Air Act Amendments: Air Quality Benefits Adjustments and Private Compliance Expenditures (2010 to 2030)

Macroeconomic Summary				
Variable	**Model Run**	**2010**	**2015**	**2020**
GDP	With Clean Air Act (billion)	$15,027	$17,338	$20,202
	Without Clean Air Act (billion)	$15,053	$17,341	$20,185
	Change (billion)	−$26	−$3	$18
	% change	−0.17%	−0.02%	0.09%
Consumption	With Clean Air Act (billion)	$10,969	$12,699	$14,881
	Without Clean Air Act (billion)	$10,970	$12,694	$14,873
	Change (billion)	−$1	$5	$8
	% change	−0.01%	0.04%	0.06%
Hicksian EV	Change (billion)	$13	$25	$34
(annual)	% change	0.09%	0.15%	0.17%
Hicksian EV	Change (billion)	$925.8		
(PV of infinite horizon)	% change	0.17%		

In the cost-only case, consumers incorporate the compliance costs in each year into their expectations and smooth their welfare over time. This results in relatively constant percentage changes in GDP, consumption, and equivalent variation. By contrast, in the case that includes benefits of the Clean Air Act, labor endowments increase over time compared to the baseline, allowing households to enjoy more leisure time (raising welfare) and supply more labor (raising GDP). Consumers will anticipate this increase in their future income and act accordingly. For instance, EV increases in 2010 although GDP falls, because consumers have more time available to enjoy as leisure. In 2015, households will continue to smooth their consumption over time and consumption increases while GDP still declines.

Average annual welfare levels (as measured by Hicksian EV) also increase over the model horizon with the Clean Air Act programs. The total present value of the gain in welfare is approximately $925.8 billion.[17] In 2020, the annual net social benefits are $16.3 billion.

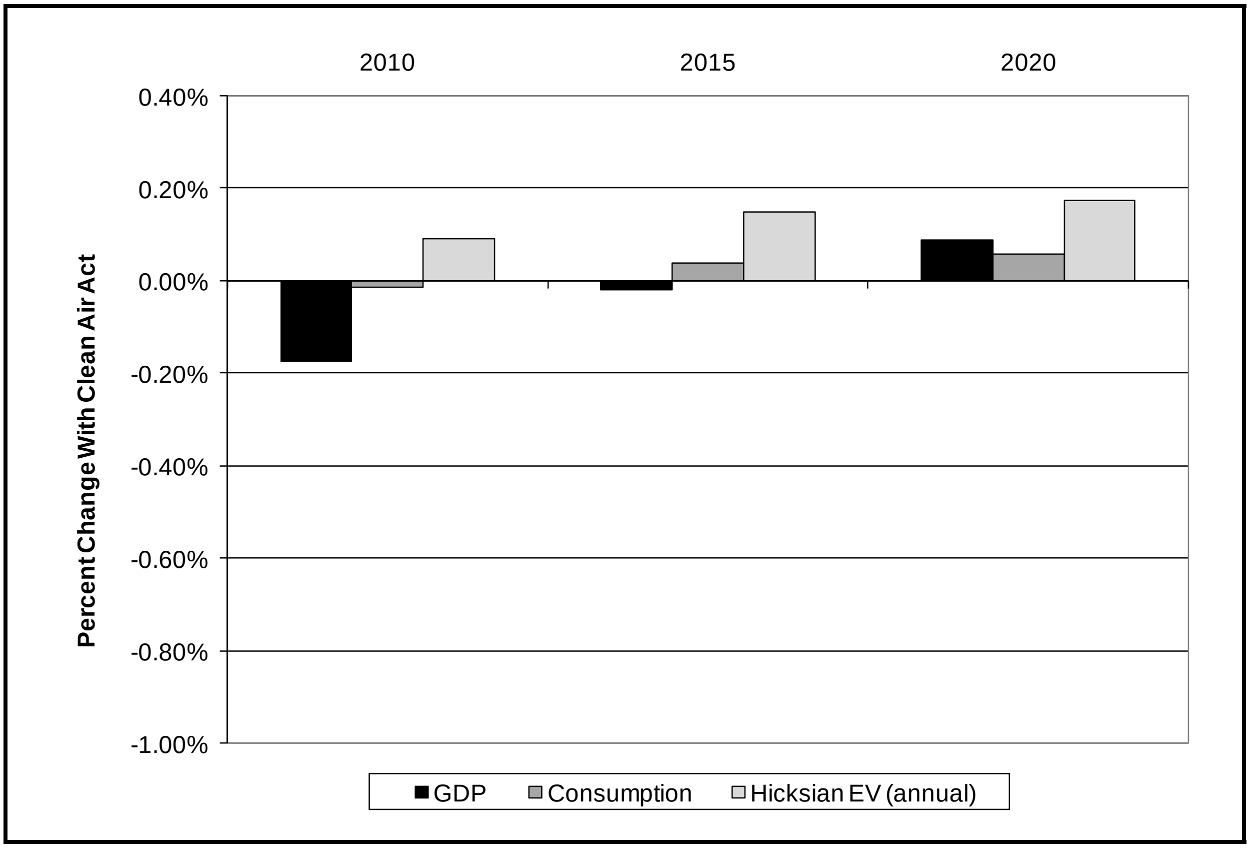

Figure 2-3. Macroeconomic and Welfare Variables Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Air Quality Benefits Adjustments and Private Compliance Expenditures (2010 to 2030)

2.2.2 Industry-Level Effects

Including benefit adjustments in the EMPAX-CGE modeling system (labor supply increase and health expenditure reduction) changes the supply of inputs and consumer demand for goods; these changes subsequently influence all industries. As shown in Figure 2-4, several manufacturing sectors experience small increases in output because they benefit from a bigger labor pool. In other manufacturing and energy sectors, the labor supply effects mitigate output

[17] Values are discounted back to 2005 at the 5% interest rate used in the model.

changes associated with private compliance expenditures. Most service sectors also increase their output; the exceptions include the health care sector, which contracts because of lower health services demand. Electricity, coal, and natural gas production tend to decline. The petroleum sector benefits from increased expenditures needed to comply with Clean Air Act programs. In particular, households increase their spending on petroleum products by purchasing higher-grade fuels. The other minerals sector experiences a large output reduction for several reasons. Most importantly, the minerals sector bears some of the highest private compliance costs relative to industry size. Additionally, the minerals sector is energy-intensive, and will reduce its output in response to higher energy prices.

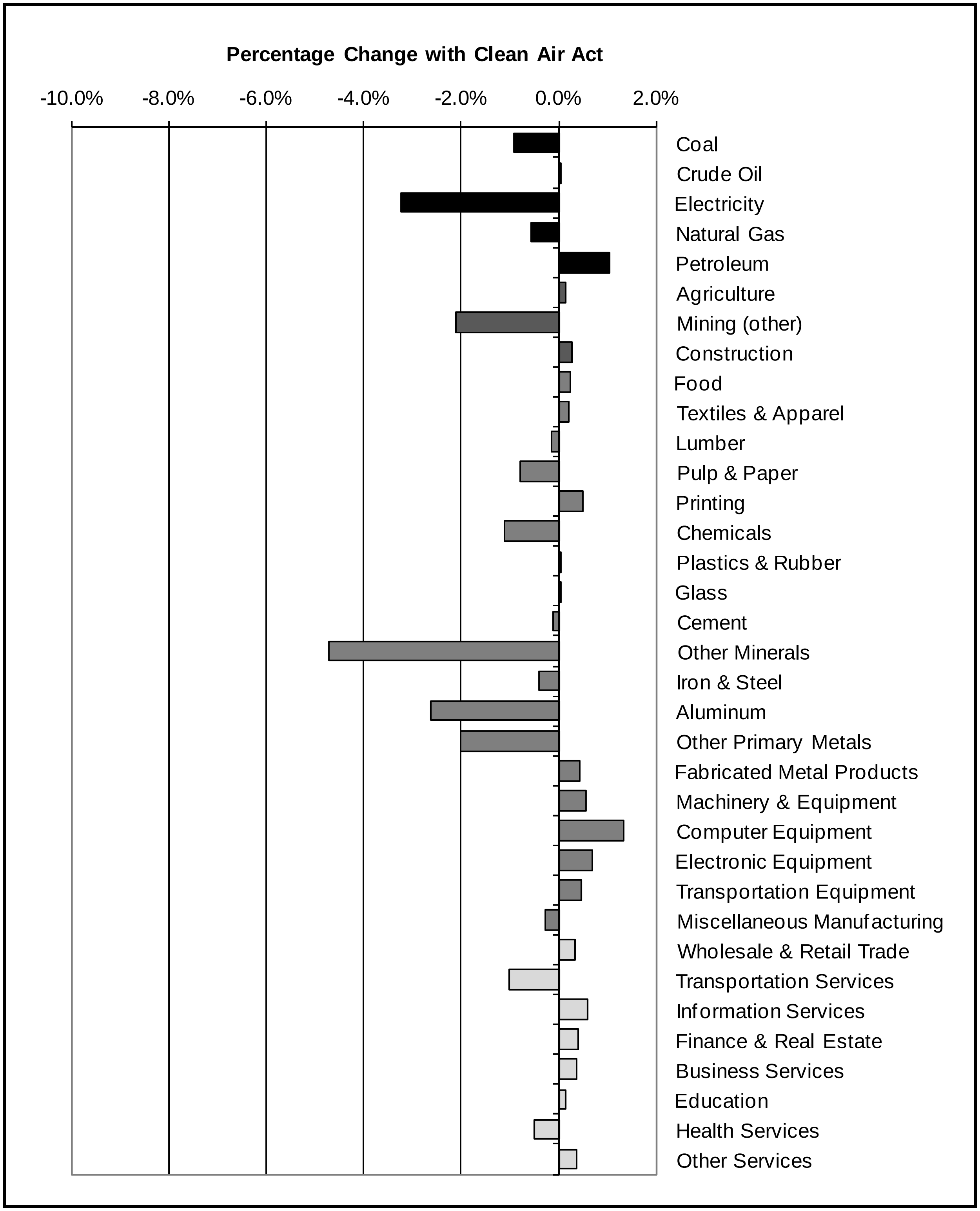

Figure 2-4. National Industry Output Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Air Quality Benefits Adjustments and Private Compliance Expenditures (2020)

SECTION 3
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APPENDIX A:
REGIONAL DETAILS

A.1 Introduction

Regional effects tend to show variation that does not appear at the national level. Several sources produce the divergences between average national impacts and regional effects and broadly include

- differences in control measures from the cost models,
- differences in regional mixes of generation technologies (coal, gas, oil, and nonfossil use) that may be averaged out at a national level,
- differences in regional production and consumption patterns for electricity and non-electricity energy goods;
- differences in industrial composition of regional economies,
- differences in household consumption patterns, and
- differences in regional growth forecasts.

Detailed regional technical information is included in the appendix for potential direct or indirect use by the Agency.

A.2 Private Compliance Expenditures Only

A.2.1 Macroeconomic Variables by Region

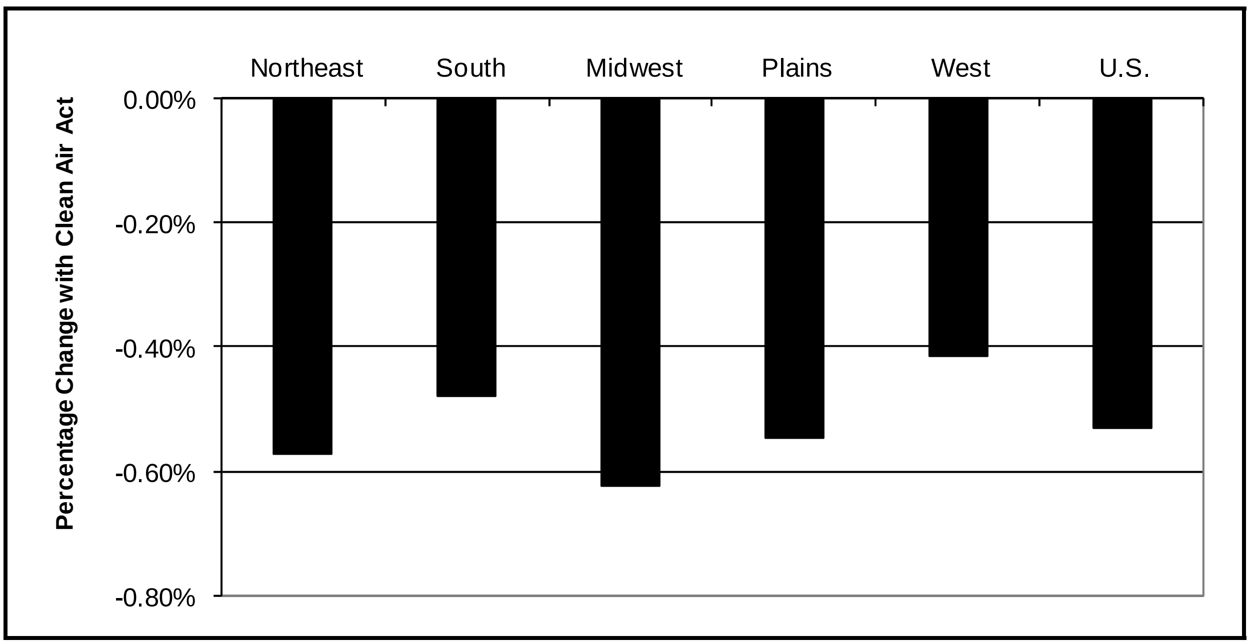

Figure A-1. Regional GDP Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Private Compliance Expenditures Only (2020)

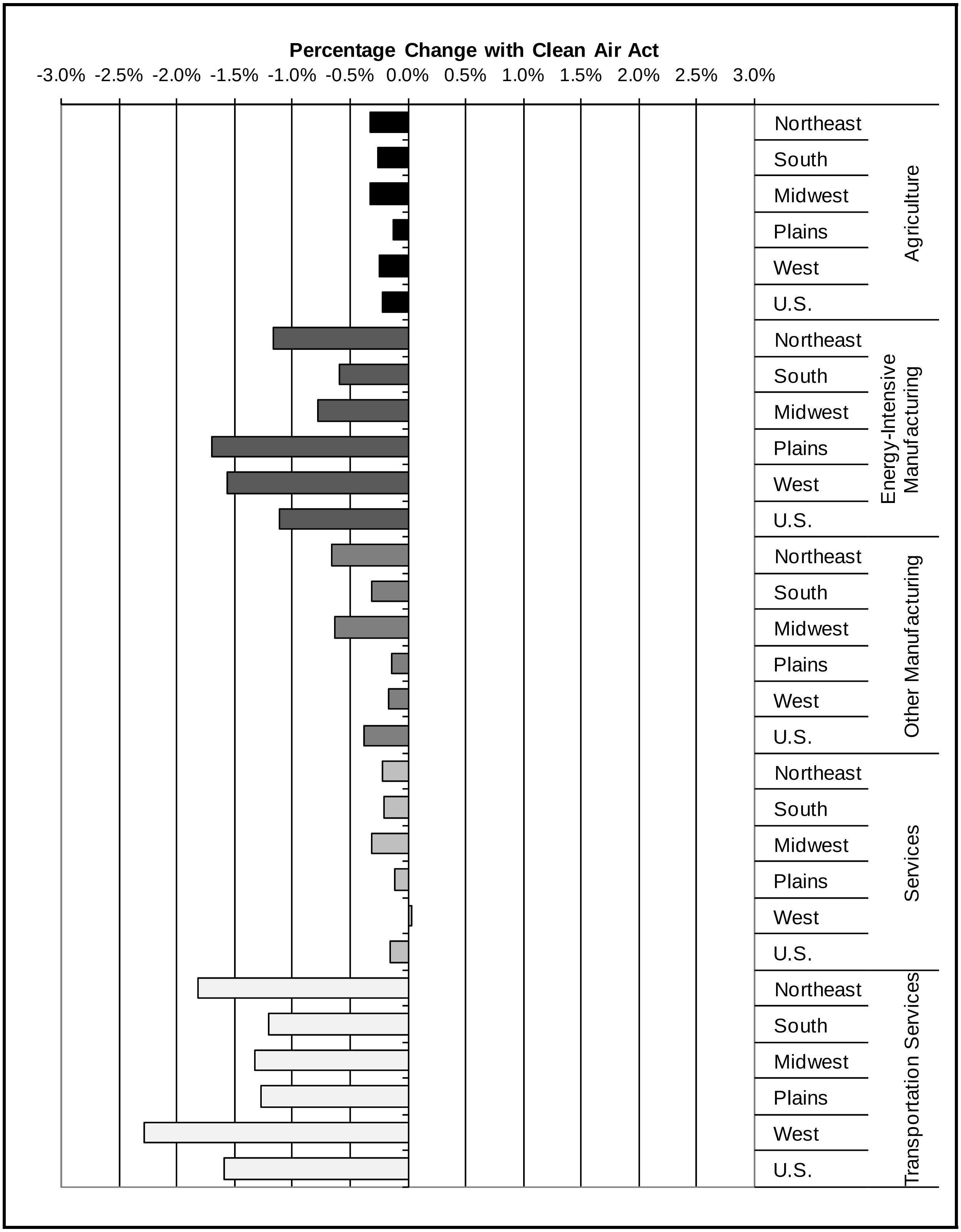

Figure A-2. Regional Industry Output Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Private Compliance Expenditures Only (2020)

A.2.2 Industry Effects by Region

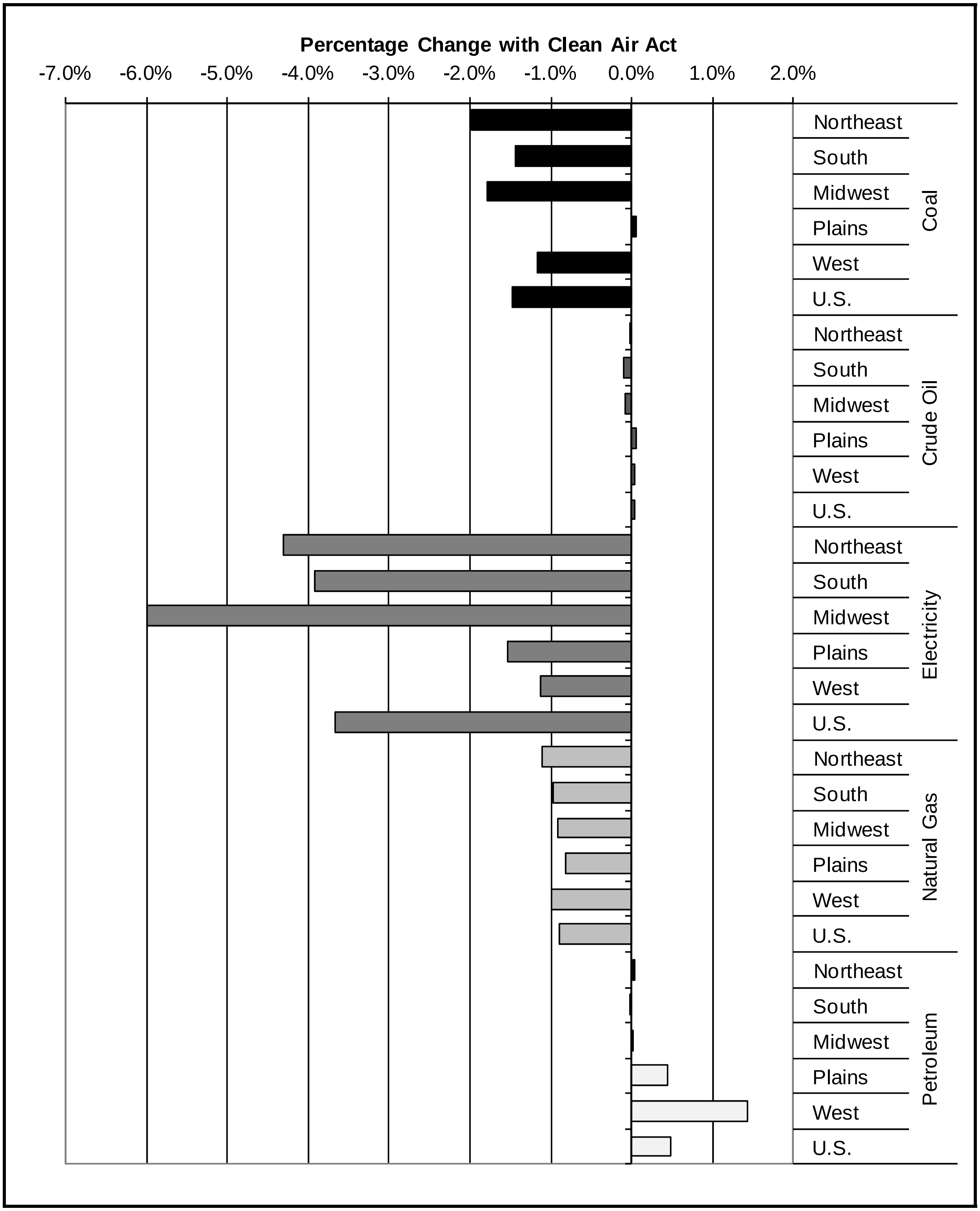

Figure A-3. Energy Industry Output Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Private Compliance Expenditures Only (2020)

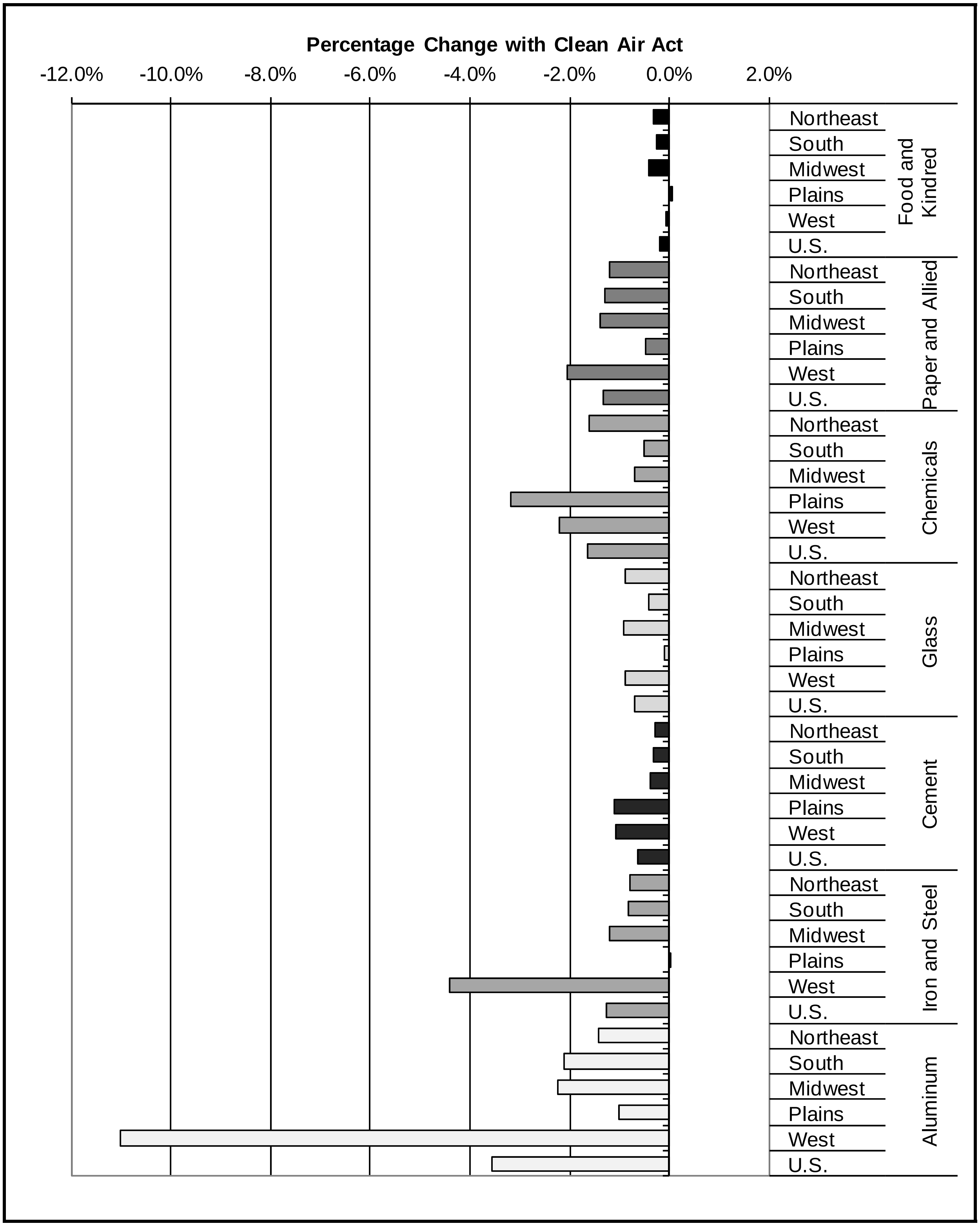

Figure A-4. Energy-Intensive Industry Output Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Private Compliance Expenditures Only (2020)

A.3 Air Quality Benefits and Private Compliance Expenditures

A.3.1 Macroeconomic Variables by Region

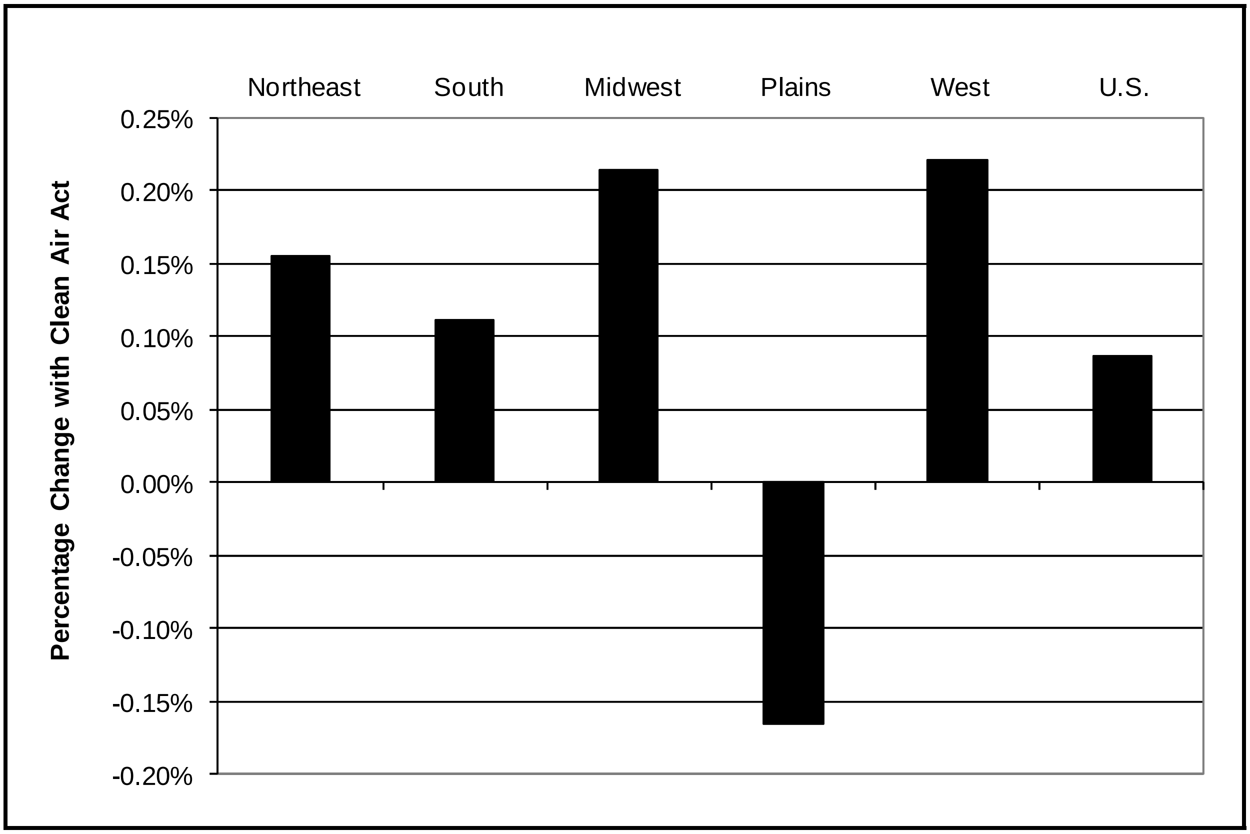

Figure A-5. Regional GDP Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Air Quality Benefits Adjustments and Private Compliance Expenditures (2020)

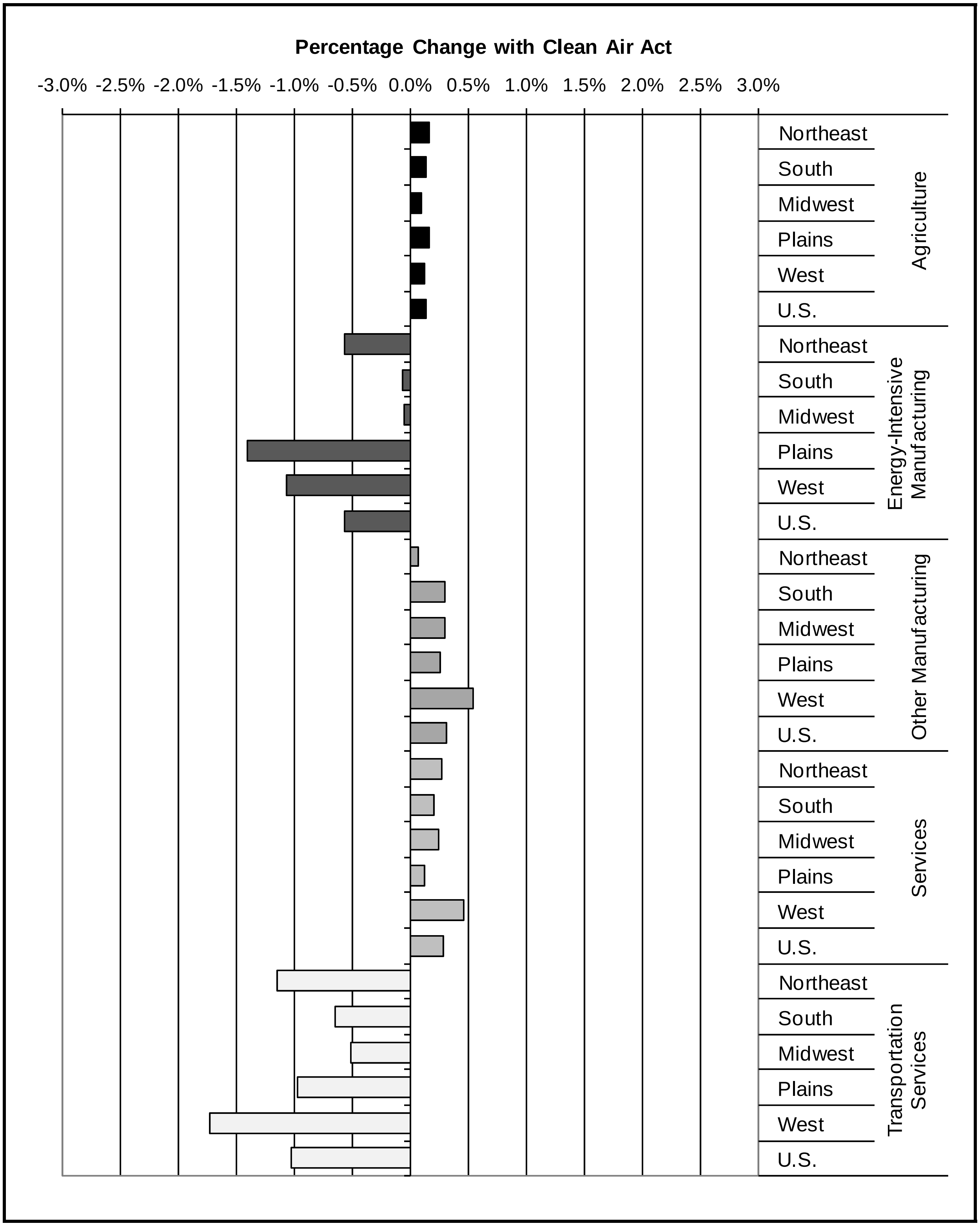

Figure A-6. Regional Industry Output Compared to Baseline without the Clean Air Act Amendments (Percent Change): Air Quality Benefits Adjustments and Private Compliance Expenditures (2020)

A.3.2 Industry Effects by Region

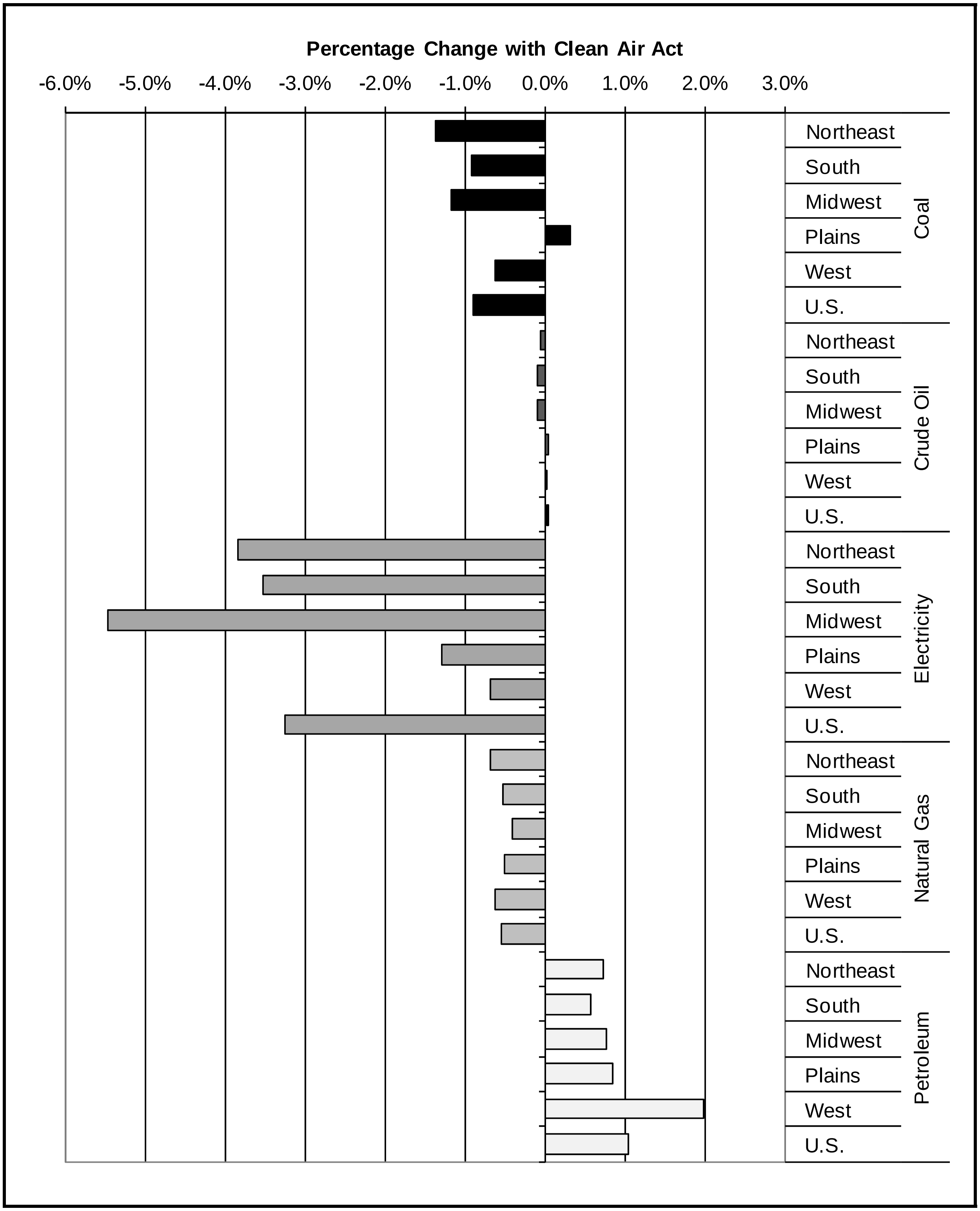

Figure A-7. Energy Industry Output Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Air Quality Benefits Adjustments and Private Compliance Expenditures (2020)

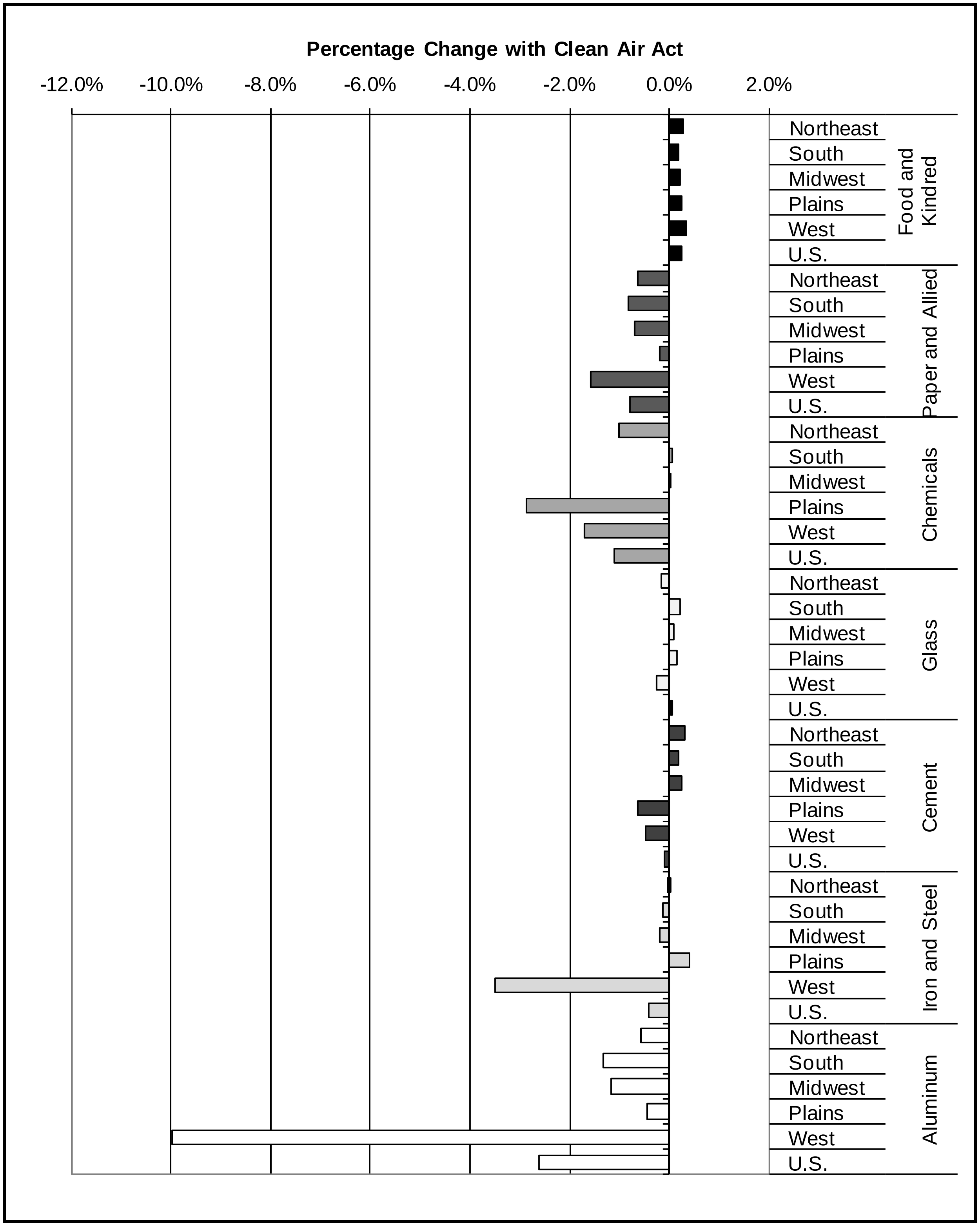

Figure A-8. Energy-Intensive Industry Output Compared to Baseline without the Clean Air Act Amendments (Percentage Change): Air Quality Benefits Adjustments and Private Compliance Expenditures (2020)