July 2004

EMPAX-CGE
Model Documentation

Final Report

Prepared for

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

Prepared by

RTI International
Health, Social, and Economics Research
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*RTI International is a trade name of Research Triangle Institute.

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CHAPTER 1
INTRODUCTION

Computable general equilibrium (CGE) models are widely used in policy analysis, including analyses of environmental issues. For environmental policies that are expected to affect many sectors either through direct compliance costs or indirectly through linkages between sectors of the economy (i.e., industries, households, government, trade), it may be important to account for these interactions and constraints. General equilibrium (GE) models account for these linkages and are more appropriate than partial equilibrium analysis of large regulations that are expected to have measurable impacts across the economy. This report describes the CGE version of Economic Model for Environmental Policy Analysis-Computable General Equilibrium version (EMPAX-CGE), which was specifically designed for use in analyses of large-scale environmental regulations.

1.1 Background

EMPAX-CGE is a regional CGE model developed by RTI International (RTI) for the Environmental Protection Agency's Office of Air Quality Planning and Standards (OAQPS). It is designed to estimate regional macroeconomic impacts of environmental regulations on the United States' economy. Many major regulations directly affect a large number of industries and/or substantially affect markets for key factors of production. In either case, substantial indirect impacts may result from changes in production, input use, income, and consumption patterns for directly affected markets. EMPAX-CGE offers the ability to trace economic impacts as they are transmitted throughout the economy and allows it to provide insights to policy makers evaluating the magnitude and distribution of costs associated with environmental policies.

The EMPAX model was first developed in 2000 to support the economic analysis of EPA regulations controlling hazardous air pollutant emissions from three combustion source categories (reciprocating internal combustion engines, boilers, and turbines).[1] It was a national multimarket partial equilibrium model with linkages between manufacturing industries and the energy sector designed to capture the effects that these combustion rules will have on other sectors of the economy through impacts on energy prices and output. A modified version of EMPAX was subsequently used to analyze the impacts of air pollution control strategies under

[1] Beach, R.H., M.P. Gallaher, B.M. Depro, and A.C. O'Connor. "Economic Impact Analysis of the Reciprocating Internal Combustion Engines NESHAP." Prepared for the U.S. Environmental Protection Agency, February 2004.

the Southern Appalachian Mountain Initiative (SAMI).[2] Over time, EMPAX has been greatly enhanced through the addition of multiple U.S. regions, more manufacturing and nonmanufacturing sectors; linkages between all sectors; more detailed energy and economic data; an improved characterization of production and consumption; and, in 2003, conversion to a GE framework (i.e., EMPAX-CGE). A key factor common across all versions of the model is the emphasis on capturing interactions between the energy sector and the rest of the economy.

EMPAX-CGE was most recently applied to estimate the macroeconomic effects of the Interstate Air Quality Rule (subsequently renamed the Clean Air Interstate Rule).[3] EPA/OAQPS expects to employ it to evaluate economic impacts as part of its review of the National Ambient Air Quality Standards (NAAQS) for particulate matter as well as other future EPA rulemakings.

1.2 History of CGE Modeling

Over the last several decades, CGE modeling has emerged as a widely accepted method for conducting empirical economic analyses because it provides the ability to integrate economic theory with real-world data. The theoretical foundation of these models is a Walrasian general equilibrium structure (Arrow and Debreu, 1954). A "general equilibrium," as described by an Arrow-Debreu model (see Arrow and Hahn, 1971), includes components such as (1) households in the economy that have an initial endowment of factors of production and a set of preferences for goods; (2) market demands that are the sum of all agents' demands and depend on prices; (3) solution prices that conform to Walras' law (expenditures equal income for any set of prices); (4) producers that maximize profits and have constant- or decreasing-returns-to-scale production functions; and (5) an equilibrium solution characterized by prices and production levels such that demand equals supply for all commodities, income equals expenditures, and production activities break even at solution prices (in the case of constant-returns-to-scale production). By combining this theoretical structure with numerical methods, CGE models can be used to estimate the effects of policy changes on all parts of the economy.

Advances in numerical simulation techniques have allowed modelers to move from simple partial equilibrium models to GE models with many more sectors and complex behaviors. This research began with Leontief (1936, 1951, 1953) who developed static input-output (I/O) models. The I/O approach employed "fixed coefficients" that did not allow production technologies to change in response to different policies. Johansen (1960) was the first to develop an applied GE model that moved away from this fixed-coefficients assumption to production functions that allow substitution among inputs and technical change. Since then, ever more

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[2] Beach, R.H., and B.M. Depro. "Competitiveness Analyses of Alternative SAMI Strategies." Prepared for the U.S. Environmental Protection Agency, March 2002.

[3] "Regional Macroeconomic Analysis of the Interstate Air Quality Rule." U.S. EPA, Office of Air Quality Planning and Standards. See www.epa.gov/clearair2004.htm.

complex models have been used to investigate a wide variety of policies from taxes to trade to the environment.

Analyses of the incidence and efficiency effects of taxes are based on the seminal works of Harberger (1959, 1962, 1966, 1974). The 1962 work laid out a two-sector GE model of taxes using standard neoclassical assumptions: supplies of capital and labor are fixed, factors are perfectly mobile across industries, and perfect competition exists in product and factor markets. Shoven and Whalley (1972, 1973) were the first to analyze taxes using a full GE structure. Subsequent works, notably Ballard et al. (1985), extended previous models by adding more sectors and modeling dynamic consequences of policies for household savings behavior. Recent works (e.g., Bovenberg and Goulder [1996], Babiker, Metcalf, and Reilly [2002], and Bovenberg, Goulder, and Gurney [2003]) have examined how existing tax distortions in an economy may interact with economic policies and alter their effects.

CGE models have been applied extensively to trade policies due to their ability to examine implications for many industries and countries simultaneously. Deardorff and Stern (1981) developed one of the first large-scale CGE trade models. It had 34 countries and 29 industries and was used to investigate the effects of changes in tariff and nontariff barriers in the Tokyo Round. Analysis of more recent trade agreements, such as the North American Free Trade Agreement (NAFTA) and the Uruguay Round of trade negotiations, have relied heavily on CGE models for assessments of impacts. These studies include U.S. International Trade Commission (1992), Francois and Shiells (1994), Martin and Winters (1996), Robinson et al. (1991), and Burfisher, Robinson, and Thierfelder (1994).

1.3 Application of CGE Models to Environmental Policies

As in other branches of economics, the use of CGE models in environmental policy applications has been growing in recent years as improvements in model structures, databases, and computer technology have reduced the costs of using these models and increased the benefits (see Adkins and Garbaccio [1999] for a bibliography of CGE models applied to environmental issues and IEC [2001] and Appendix A of EPA [2003] for an overview of selected CGE models used in environmental analysis). Regulations may affect the economy through their influence on rates of technological innovation, the level of private investment and trade, and the location decisions of firms and workers. A major strength of CGE models for regulatory analysis is their ability to implicitly take these effects into account. Regulations that directly raise costs of production and/or prices in an industry can indirectly discourage both investment in and exports from that industry as well as industries that rely on that sector for productive inputs. In CGE models, regulatory compliance costs lead to reductions in investment as a result of lower returns to capital while exports are discouraged by higher terms of trade (the ratio of domestic to world prices).

The energy sector plays a unique role as an input into essentially every other sector of the economy while simultaneously being one of the largest contributors to air pollution. As a result of its importance, one of the earliest areas of application of CGE models to environmental issues, beginning in the mid- to late-1980s, was to energy policy modeling (e.g., Bergman [1988]; Despotakis and Fisher [1988]). Subsequently there has been an emphasis on the energy sector in almost all CGE models used to analyze large-scale environmental regulations. Often, the energy sector bears a large share of the direct costs, and resulting changes in prices and quantities in the energy market can have a substantial impact on the rest of the economy.

Another early application of CGE models to environmental policy (and still one of the most common) was in the analysis of economy-wide impacts associated with restrictions on or required reductions for emissions of pollutants. Environmental standards, taxes, or tradable permits lead to direct costs, including payments to government (in the case of taxes or auctioned permits), permit trade expenditures, and abatement expenditures. However, direct costs do not necessarily measure social costs nor the distributional implications that are important to policy makers/agencies who seek to design optimal policies from a societal viewpoint. To estimate the social costs of environmental programs, one must capture the sum of direct, indirect, and induced costs.[4] This means modeling all relevant linkages, substitution possibilities, technical changes, and dynamic processes that are affected by environmental programs throughout the economy. The CGE framework has proven to be a valuable tool for capturing these kinds of complex effects because of its ability to model individual agent behavior, while at the same time depicting the workings of an entire economy. The Intertemporal General Equilibrium Model (IGEM), developed by Jorgenson, Ho, and Wilcoxen, is an example of a CGE model that has been used in many different studies of the impact of environmental regulations on economic growth since the early 1990s (e.g., Ho and Jorgenson [1998]; Jorgenson [1998]; Jorgenson and Wilcoxen [1990a], [1990b], [1993a], [1993b], [1993c], [1993d], [1997], [1998]) as well as an assessment of the social costs associated with the Clean Air Act. Hazilla and Kopp (1990) used a model that is very similar to IGEM in an analysis of the social costs of the Clean Air and Clean Water Acts.

CGE models have also routinely been applied to evaluate impacts of climate change policies. Studies include Rose and Oladosu (2002), Bernstein et al. (1999), Harrison and Rutherford (1998), Jorgenson and Wilcoxen (1993b), McKibbin et al. (1999), Manne and Richels (1997), and Bovenberg and Goulder (1996), among others. Most of these models provide results at the national level, but efforts have been made to model impacts on different regions of the United States. The Multi-Region National (MRN) model, which is a dynamic CGE model that has been used primarily to estimate impacts associated with various energy

[4] Direct effects are experienced by a specific industry. Indirect effects capture how direct effects spill over into other industries, and induced effects cover how income changes from direct/indirect effects affect the economy.

policies and hypothetical carbon target policies (Balistreri and Rutherford, 2001), is capable of providing results down to the state level through a decomposition of estimation into three separate models solved sequentially.

Since the mid-1990s, numerous studies have relied on CGE models to examine the interaction between environmental regulations and tax-induced distortions in the labor market, often referred to as tax-interaction effects (TIEs). Parry (1997), Goulder et al. (1999), and Fullerton and Metcalfe (2001) are notable examples of this literature. If one performs single-market analysis of a tax policy, say, or an environmental regulation, then one assumes that there are no other-market distortions or that the exacerbation and amelioration of other-market distortions caused by the intervention in question cancel one another out. The TIEs literature argues that in the case of environmental policy (as well as agricultural policy and trade policy; see Parry [1999] and Williams [1999]) the other-market effects do not cancel out. In particular, the nature of environmental regulation—through command and control, pollution taxes, or quota restrictions on pollution—systematically worsens the distortion in the labor market that arises from the existing income tax (i.e., any decrease in the real wage tends to further decrease labor supply from an already nonoptimal point). This literature has potentially important implications for the way that social costs of environmental regulations are calculated. The findings in this literature argue for the use of CGE models rather than single-sector models in estimation of the social costs associated with regulation to account for the potentially large tax interaction effects that may result. However, some have shown that a more complete accounting of environmental regulations, and benefits in particular, may have offsetting effects on social costs.

Some more recent studies are attempting to account for environmental benefits within CGE models. Perroni and Wigle (1994) argue that it is essential to build the benefits of environmental improvement into CGE models. In their model, there is an initial endowment of environmental quality, some of which is consumed by activities that generate pollution. Firms can abate pollution by substituting other inputs (e.g., machinery) for emissions. The household utility function in this model includes environmental quality as a consumption good with increasing marginal utility as income rises. They use the model to explore the interactions between trade policy and environmental policy. Another example of this line of research is Smith et al. (2003), where the benefits of ozone reductions in the Los Angeles Air Basin are estimated in a general equilibrium framework.

1.4 Overview of a Standard CGE Model

CGE models explicitly capture all of the flows of factors and commodities in an economy. Unlike I/O analyses, which focus on the production side of the economy and rely on exogenous multipliers to estimate demand effects, CGE models include income flows, distributional effects, and changes in behavior in response to price changes. By modeling both producer and consumer behavior, CGE models are able to estimate how policy effects will ripple through the entire economy in a manner consistent with economic theory.

Figure 1-1 illustrates a simplified version of the circular flows in an economy considered by a CGE model.[5] Households own factors of production (capital, labor, and natural resources) and supply them to firms. These factor sales generate income for households. Firms produce output by combining productive factors with intermediate inputs of goods and services from other industries. Output of each industry is purchased by other industries and consumers using the income received from sales factors. Goods and services can also be exported, and imported goods can be purchased from other countries.

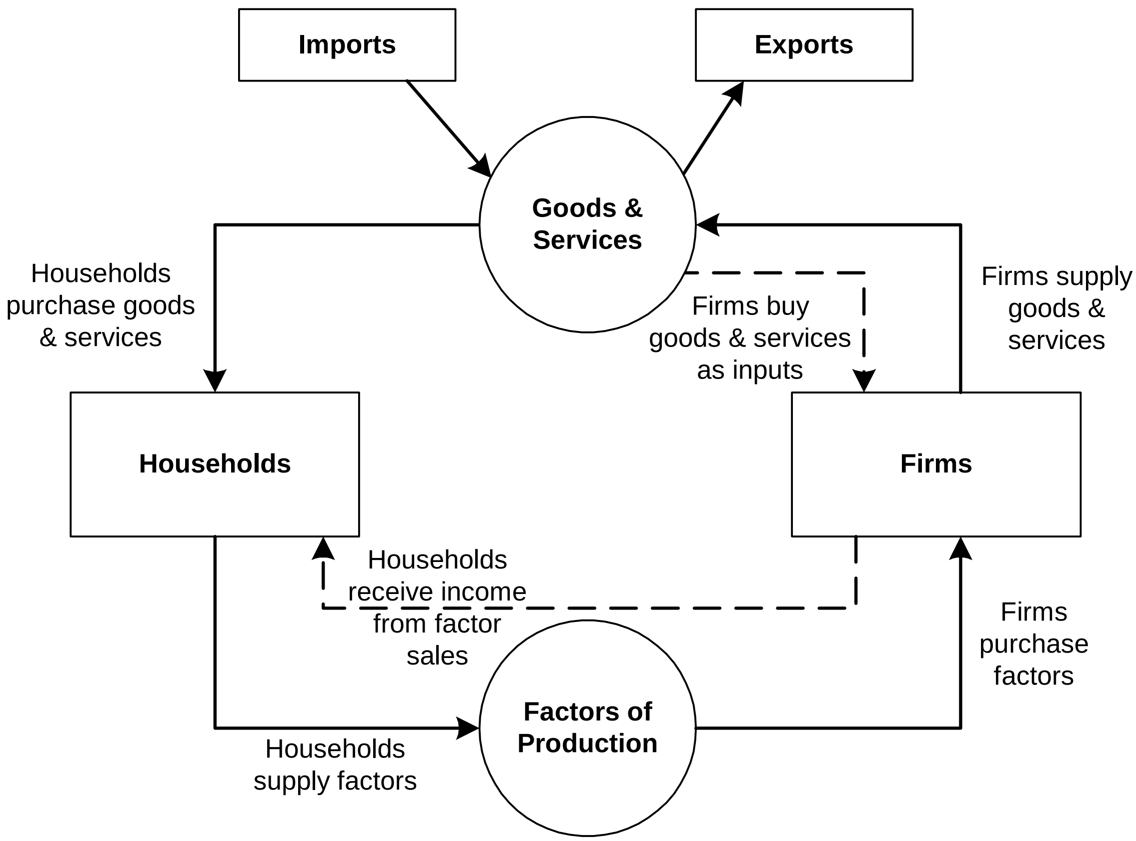

Figure 1-1. Circular Economic Flows within CGE Models

The "general equilibrium" component of CGE modeling requires that all sectors in the economy must be in balance and all flows must be accounted for. Every commodity that is produced must be purchased by firms or consumers within the United States or exported to

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[5]Although this diagram ignores government, investment, and some features of foreign agents for the sake of simplicity, CGE models usually cover these interactions as well.

foreign consumers. Prices of these goods reflect all costs of production. Households receive payments for their productive factors and transfers from the government (not shown in Figure 1-1), and this income must equal consumer expenditures. In aggregate, all markets must clear, meaning that supplies of commodities and factors must equal demand, and the income of each household must equal its factor endowments plus any net transfers received.

Firms in a CGE model are assumed to maximize profits, which are the difference between revenues from sales and payments for factors of production and intermediate inputs. Profit maximization is done subject to constraints imposed by available production technologies. According to economic theory of producer behavior, firms will use each type of input up to the point where the marginal revenue received from employing an additional unit of an input is equal to the marginal cost of purchasing that input (i.e., MRP = MC).

Typically, production technologies are specified using constant elasticity of substitution (CES) functions that describe how different types of inputs can be substituted for each other (as discussed in Chapters 2 and 3). The extent of these substitutions is determined by elasticities that control how easily trade-offs among inputs can be made. Unlike I/O models or partial-equilibrium models using fixed coefficients in production, this model structure allows producers to change the technology employed to manufacture goods. If, for example, energy prices rise, an industry can shift away from energy by employing more capital, labor, or intermediate inputs as allowed for by the CES equations. This allows a CGE model to consider energy efficiency improvements as businesses substitute away from energy and into less energy-intensive methods.

Households are assumed to maximize utility received from consumption of goods and services, subject to their budget constraint. CES functions are used to describe these utility functions, which show how willing and able households are to substitute among consumption goods in response to price changes. Because utility functions employed by CGE models are based on neoclassical economic theory, it is generally possible to estimate how a policy will affect consumers’ standard of living as measured by changes in welfare, or Hicksian equivalent variation (EV). Models without a strong theoretical basis are only able to examine changes in variables like gross domestic product (GDP), which may be unrelated to consumers’ standard of living.

1.5 Summary of EMPAX-CGE Features

Several versions of EMPAX-CGE have been developed for EPA:

- two static versions (national and regional) for investigating long-run policy effects on a wide range of industries and
- a dynamic regional version to examine policies with varying effects over time.

The theoretical structures of all versions are similar, although the dynamic version has fewer sectors and regions because of computational constraints and the need for additional features to model investment decisions and energy markets over time (i.e., production, consumption, and price forecasts). Both the static and dynamic versions are described in detail in the following chapters.

The model structure and underlying databases of all EMPAX-CGE versions are designed to be capable of estimating macroeconomic impacts of environmental regulations on different industries and regions in the United States. Although the theoretical structure of EMPAX-CGE is similar to other CGE models looking at energy policies, it includes additional regional information and uses a wide range of sources for its energy data. The regional disaggregation is essential because many environmental policies can have substantially different impacts across areas of the country. Use of the most complete data sources to characterize energy production and consumption by firms and households is also critical when modeling policies that may have significant implications for energy markets.

Aside from dynamics, the main difference between the static and dynamic versions of EMPAX-CGE is the level of aggregation. The national-level static version has 384 sectors, while the regional static version has 41 commodities (seven of which are types of energy), produced by 40 sectors in 10 regions. The dynamic version of EMPAX-CGE has 17 sectors (six of which are types of energy) and five regions. Computational issues limit its size to fewer industries and regions than the static model because it must solve for multiple time periods. All versions of the model are built using the same dataset and characterizations of firm and household behavior. Responses in the static version are intended to represent long-run changes in the economy, while the dynamic version is able to examine transitional effects as the economy responds to policies over a period of years.

Distortions associated with the existing tax structure in the United States have been included in EMPAX-CGE (as detailed in Chapter 7). A wide range of theoretical and empirical literature has examined "tax interactions" and found that they can substantially alter costs of environmental (and other) policies. The economic database used by EMPAX-CGE (as detailed in Chapter 4) includes information on some types of taxes, which have been combined with other sources to cover important distortions from capital and income taxes.

To characterize households, the IMPLAN database was used to distinguish nine groupings classified by income. Because environmental policies can potentially influence income distributions and affect households in substantially different ways, these data can be used to define several households in each region of the model. The static versions of EMPAX-CGE are capable of running all nine household groupings, while computational issues limit the dynamic regional version to four households in each of five regions for a total of 20 households.

1.6 Outline of Model Documentation

The remainder of this report includes the following:

- Chapter 2—Summarizes the EMPAX-CGE model structure, scope, and types of policy evaluations that can be conducted.
- Chapter 3—Discusses additional details of producer and consumer behaviors and presents more information on production technologies of different industries.
- Chapter 4—Examines the data sources used by EMPAX-CGE and how the energy data are integrated with the economic data.
- Chapter 5—Describes the use of EMPAX-CGE for policy applications. It also presents information on how EMPAX-CGE allocates environmental protection expenditures across types of equipment purchases and factor inputs by businesses in order to reduce emissions.
- Chapter 6—Discusses the extensions that have been made to the static version of EMPAX-CGE to incorporate dynamic responses over time.
- Chapter 7—Covers the inclusion of taxes in the model. This allows EMPAX-CGE to consider how interactions between existing taxes and environmental policies may affect model results.
- Appendix A—Summarizes the features of selected CGE models (IGEM and Argonne Multi-sector Industry Growth Assessment Model [AMIGA]) and EMPAX-CGE.
- Appendix B—Shows the various methods by which EMPAX-CGE can be linked to the Integrated Planning Model (IPM) model to estimate macroeconomic effects of electricity policies. It also illustrates the User Interface that automates a linkage between EMPAX-CGE and the IPM and AirControlNet models, and allows the user to determine how EMPAX-CGE will be run.
- Appendix C—Presents the 384 sectors that are included in the national static version of EMPAX-CGE.

CHAPTER 2
OVERVIEW OF EMPAX-CGE

This chapter provides an overview of EMPAX-CGE covering the general theoretical structure, industry and regional characterizations, and data sources. Subsequent chapters provide additional details on each of these topics.

2.1 General Structure

The theoretical framework used by EMPAX-CGE is an Arrow-Debreu general equilibrium. Firms maximize profits subject to technology constraints, and consumers maximize utility subject to budget constraints. All markets must clear so that supply of goods and services is equal to demand. In addition, income of each agent must equal their factor endowments plus any net transfers.

EMPAX-CGE combines a variety of economic and energy data sources (as detailed in Chapter 5) to characterize energy production and consumption decisions with sufficient regional and industry detail to allow investigation of policies that may alter these decisions. These data are contained in a social accounting matrix (SAM) that shows current production technologies and demands by agents in the economy. The economic data in the SAM come from state-level information provided by the Minnesota IMPLAN Group,[1] while the energy data come from the Energy Information Administration (EIA) at the Department of Energy. .

The three versions of EMPAX-CGE employ these data sources to describe regions, industries, and commodities according to the dimensions shown in Table 2-1. The national static version of EMPAX-CGE has been developed for policy investigations that require a substantial level of detail in the representation of manufacturing industries without a need for regional detail (see Appendix C for a complete list of included sectors). The regional static version of EMPAX-CGE uses available data sources to describe 40 sectors and 41 commodities. It includes 10 regions covering the United States, which are combinations of states selected to approximate regions defined as distinct electricity markets by the North American Electric Reliability Council (NERC). Although the dynamic version of EMPAX-CGE contains fewer regions and industries because of computational limits (5 and 17, respectively), the underlying database and model structure are the same. Consequently, although the discussions in Chapters 2 and 3 focus on the regional static version, the model structure for the dynamic version is substantially similar (differences are highlighted in Chapter 6).

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

Table 2-1. Dimensions of EMPAX-CGE Versions

Version	Regions	Industries	Commodities
Static			
National	1	384	385
Regional	10	40	41
Dynamic			
Regional	5	17	16

The baseline data used by static EMPAX-CGE are benchmarked using EIA forecasts to represent the economy in a particular year in the future, usually 2010, 2015, or 2020. From this starting point, it estimates long-run economic effects for a policy in question. The dynamic model uses baseline data representing the economy in 2005 and solves in 5-year increments out to 2050. For years following 2005, the dynamic version incorporates energy consumption and production forecasts generated by EIA.

All versions of EMPAX-CGE employ a nested CES model structure. These types of nested equations are used by CGE models to portray the types of substitution possibilities available to producers and consumers. Figure 2-1 illustrates this general framework and gives a broad characterization of the model. The diagram begins at the top with household decisions on consumption, followed by the trade structures used to generate aggregate consumption goods from domestic and imported varieties, and finally covers the production functions that provide the goods. Subsequent discussion gives more details about the decisions at each level of the figure, and Chapter 3 provides specifics about the production and consumption functions used.

2.2 Households

As appropriate, each region within EMPAX-CGE contains one or more representative households. As shown at the top of Figure 2-1 (i.e., Level 1), the household(s) maximizes utility received from consumption of goods and leisure time. Income used to purchase goods comes from sales of factors owned by the households, which include capital, labor and natural resources. As shown, in Level 2, households decide among various consumption goods according to a Cobb-Douglas specification. This structure allows households to shift consumption of goods and services in response to policies. If a good’s price increases, consumers can purchase less of that good and more of other types of goods. Effects of a policy on households’ standard of living (or, more formally, their welfare as measured by changes in Hicksian equivalent variation) are determined by how willing and able they are to alter their consumption patterns.

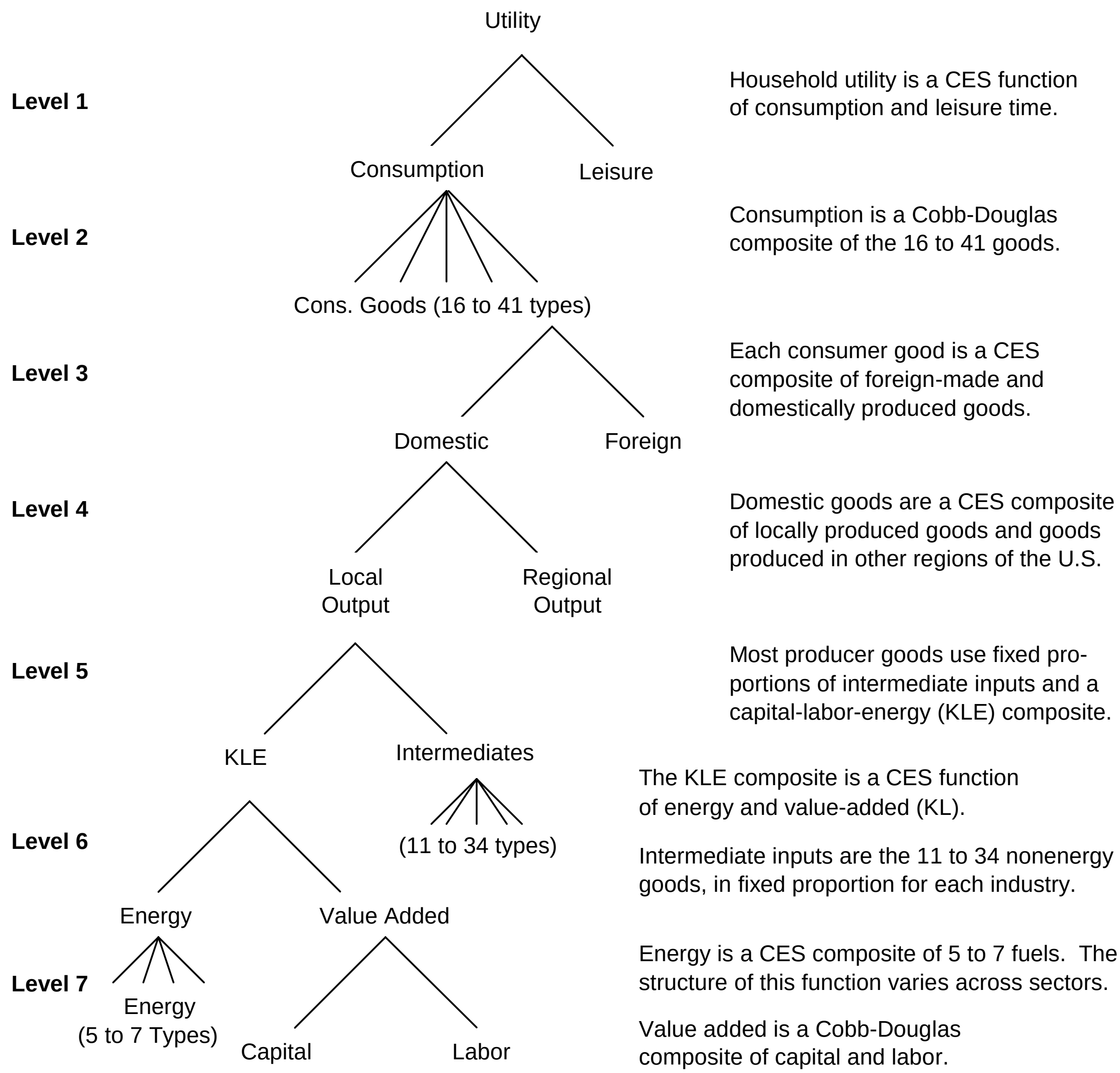

Figure 2-1. General EMPAX-CGE Structure

Note: The number of goods depends on the version of EMPAX-CGE being used (statistics shown in Figure 2-1 refer to the regional static and dynamic versions of the model).

2.3 Trade

Goods and services consumed by households (and the intermediate materials used by firms) are a composite bundle of goods made up of locally manufactured commodities, commodities from other regions in the United States, and foreign (non-U.S.) goods. As in most CGE models, these composite goods are formed using the Armington (1969) assumption that goods are differentiated by source. In other words, agents have different preferences for a commodity produced by a foreign firm than for a similar commodity produced in their home region or other parts of the United States.

The CES nesting structure behind the Armington assumption is illustrated in the third and fourth levels of Figure 2-1. The third level combines domestically produced goods from U.S. firms with foreign imports. This allows consumers and firms to express preferences for domestic goods over foreign goods and vise versa. The fourth level combines local commodities produced within a region with commodities made by firms in other regions of the United States. By using this type of nesting structure, a CGE model can express, for example, how household purchases of a total number of cars are made up of both domestic and foreign cars, and can describe how willing consumers are to switch among manufacturers.

2.4 Production Activities

The production activities used by most industries are illustrated in Levels 5, 6, and 7.[2] Each industry maximizes profits, equal to the difference between revenues from sales and payments for factors and intermediate inputs, subject to technology constraints. This nested CES structure is similar to those employed by other CGE models designed to investigate the effects of policies. The structure allows producers to change the technology they use to manufacture goods. If, for example, electricity prices rise, an industry can shift away from electricity and into other types of energy. It can also elect to employ more capital or labor in place of electricity, which allows EMPAX-CGE to model improvements in energy efficiency.

The manner in which energy efficiency improvements can be achieved is controlled by the nesting structure of the production activities. Level 5 shows how the capital-labor-energy composite good (KLE) is combined with intermediate materials inputs to produce final output. The assumption typically made in CGE models is that this is done in fixed proportions, which implies that businesses must either invest in more capital goods (i.e., new equipment) or hire more workers to achieve energy efficiency improvements. Level 6 controls these improvements by specifying how value added (the combination of capital and labor) can be substituted for energy. The seventh level then determines how capital and labor can be substituted for each other and, in the nest of the seven different types of energy, specifies how one type of fuel can be used in place of another.[3]

The ease with which firms can switch among production inputs is controlled by elasticities of substitution. Elasticities relating to energy consumption are particularly important

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[2]Natural resources (coal, crude oil, and natural gas) and agriculture have slightly different production structures to represent limits imposed on production by use of resources that are in fixed supply. These differences are discussed in Chapter 3.

[3]Specification of the energy nests depends on the industry in question, as discussed in Chapter 4.

for the types of policies investigated by EMPAX-CGE. If, for instance, an industry is able to substitute away from energy with relative ease, the price of its output will not change much when energy prices vary. These elasticity assumptions, which are based on empirical estimation and modeling research by Massachusetts Institute of Technology's (MIT's) Joint Program on the Science and Policy of Global Change, are discussed in more detail in Chapter 3.

2.5 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. The IMPLAN economic database used by EMPAX-CGE includes information on taxes such as indirect business taxes (all sales and excise taxes) and Social Security taxes. However, IMPLAN reports factor payments for labor and capital at their gross-of-tax values, which necessitates use of additional data sources to determine personal income and capital tax rates. Chapter 7 describes this process and resulting model estimates of the burden imposed on households by the current tax structure in the United States.

2.6 Government and Investment

Government purchases and use of investment goods to form capital stocks are tracked in the IMPLAN economic data used by EMPAX-CGE (as detailed in Chapter 4). All government expenditures are financed by tax receipts and transfers from households. Although investment behavior plays an important role in the dynamic version of EMPAX-CGE (as detailed in Chapter 6), in the static versions of EMPAX-CGE, investment decisions are not linked to the formation of capital for future production. Therefore, in the static versions of the model, investment goods and government expenditures are determined from the IMPLAN data and are maintained at their current baseline levels and do not enter the optimization decisions of households and businesses.

2.7 Industries in EMPAX-CGE (Static Versions)

The national static version of EMPAX-CGE includes 384 industries and 385 commodities (as detailed in Appendix C), while the regional static version includes 40 industries and 41 commodities. The number of commodities is different than the number of sectors because (1) the electricity sector is divided into two components, fossil-based and nonfossil-based generation, each producing the same type of electricity, and (2) the petroleum refining industry produces three goods: distillate fuel, motor gasoline, and other petroleum. Table 2-2 presents the industries in the regional static version and their associated North American Industry Classification System (NAICS) codes.

Industries in the regional static version of EMPAX-CGE have been selected based on two factors: (1) the desire to distinguish segments of the economy most likely to be affected by energy/environmental policies and (2) availability of energy consumption data. Several small

Table 2-2. Characterization of Industries in EMPAX-CGE (Regional Static Version)

Classification	EMPAX Industry	NAICS
Energy	Coal	2121
	Crude Oil	211111 (except for natural gas)
	Electricity *(fossil and nonfossil)*	2211
	Natural Gas	211112, 2212, 4862
	Petroleum Refining[a]	324
Nonmanufacturing	Agriculture	11
	Construction	23
	Mining	21 (except coal, crude oil, or natural gas)
	Services	42, 44-45, 51-56, 61-62, 71-72, 81, 22 (except electricity or gas)
	Transport by Air	481
	Transport by Freight Truck	484
	Transport by Railroad	482
	Transport by Water	483
	Transport by Other	485, 486 (except gas distribution), 487, 488
Manufacturing	Food	311
	Beverages and Tobacco	312
	Textile Mills	313
	Textile Product Mills	314
	Apparel	315
	Leather	316
	Lumber and Wood	321
	Paper	322
	Printing and Publishing	323
	Chemicals	325
	Rubber and Plastic	326
	Glass	3272
	Cement	3273
	Other Nonmetallic Minerals (not including Glass or Cement)	327
	Iron and Steel	3311
	Aluminum	3313
	Other Primary Metals (not including Iron/Steel or Aluminum)	331
	Fabricated Metal	332
	Machinery	333
	Computer and Elec Equipment	334
	Electronic Equipment	335
	Transportation Equipment (except Motor Vehicles)	336
	Motor Vehicles	3361, 3362, 3363
	Furniture	337
	Miscellaneous	339

[a]Output of the petroleum refining industry is classified as either distillate, motor gasoline, or other petroleum.

Note: Appendix C contains listings of industries included in the national, static version of EMPAX-CGE.

industries (e.g., glass and cement) have been kept separate because they are relatively energy intensive and are more likely to be subjects of air pollution control programs, based on their combustion processes, than other types of firms classified under the same three-digit NAICS code.

The number of industries is also controlled by available energy data. As discussed in Chapter 4, the energy production and consumption data in EMPAX-CGE comes from a variety of government sources including the Energy Information Administration's Annual Energy Outlook (AEO) forecasts and the Manufacturing Energy Consumption Survey (which gives current energy consumption by industries). This information is combined with the IMPLAN economic data to preserve as much industry detail as is feasible, resulting in the 40 sectors included in the regional static version of EMPAX-CGE.

Representation of the 40 industries shown in Table 2-2 requires most of the energy consumption data that are available from EIA. However, in some instances it is desirable to represent a wider range of industries for analyses of policies with concentrated scope and effects. For this reason, the national static version of EMPAX-CGE separates out the 25 manufacturing industries in Table 2-2 into 372 industries (for a total of 384 sectors because energy and nonmanufacturing industries are maintained). This is accomplished by using economic data on nonenergy production inputs to sectors at approximately the 6-digit NAICS level. It is assumed that energy intensities of these detailed manufacturing sectors are equivalent to those of the ones from which they have been disaggregated. Appendix C provides a listing of industries in the national static version of EMPAX-CGE.

2.8 Regions in EMPAX-CGE (Regional Static Version)

As shown in Figure 2-2, the regional static version of EMPAX-CGE contains 10 regions (the dynamic version contains five regions, as described in Chapter 6). These regions have been defined based on a variety of considerations: expected regional distribution of policy impacts investigated by EMPAX-CGE, computational limits on model size, and availability of economic and energy data.

Many environmental policies have significant implications for methods of generating electricity. In addition, existing generation technologies vary substantially across the United States, implying that regions will experience different effects from policies. Given these considerations, EMPAX-CGE regions have been designed to follow, as closely as possible, the electricity market regions defined by NERC. Unfortunately, economic data and information on nonelectricity energy markets are generally only available at the state level (see Chapter 4 for a discussion of EMPAX-CGE data sources). This necessitates an approximation of NERC regions in EMPAX-CGE that follows state boundaries, as indicated in Figure 2-2.

Figure 2-2. Regions in EMPAX-CGE

**WSCC* also includes Alaska and Hawaii.

2.9 Social Accounting Matrix

EMPAX-CGE, like many other CGE models, relies on a SAM to provide the baseline economic data for the model. These data describe initial economic conditions in a given year. A SAM shows values of output, payments by firms for factors of production and intermediate inputs, household income and consumption, government purchases, investment, and trade flows. It characterizes existing production technologies available to industries in the economy by showing what inputs are used to produce output.

By combining this information on current technologies with the production nesting structure and elasticities of substitution as detailed in Chapter 3, EMPAX-CGE is able to estimate how firms will respond to changes in prices of their inputs by substituting among productive factors to manufacture output in the least-cost manner. In addition, data in the SAM, together with households' utility functions, portray initial consumer demands and how they will change in response to policies.

The SAM used by the static version of EMPAX-CGE is calibrated to represent a specific point in time, which is selected based on the policy year of interest. It is calibrated to represent the economy for the year in question through a process described in Chapter 4. The main focus of the calibration process is to ensure that data in the SAM reflect energy production and consumption patterns that are expected in the economy in the baseline forecast. Without an adequate characterization of initial energy use, it would be infeasible to estimate effects of policies that will alter these patterns. The dynamic version of EMPAX-CGE relies on the same database for its initial year but requires additional calibration work to replicate baseline economic forecasts (as detailed in Chapter 5).

2.10 Policy Evaluation

The EMPAX-CGE model can be used to analyze a wide array of policy issues, including such items as analyses of the economic costs of environmental regulations, distributional effects of policies across different industries and regions of the United States, the effects of energy efficiency improvements, and comparisons between command and control policies and market incentives, among many other possibilities. The use of comprehensive EIA data on the energy sector and energy use by the industrial, commercial, and residential sectors allows for detailed examinations of items such as

- how changes in electricity prices affect business and consumer choices,
- the implications of changes in fuel use by firms for fuel markets, and
- how changes in nonelectricity energy prices affect industry and consumer behavior.

An essential component of EMPAX-CGE's ability to analyze environmental policies is its inclusion of information on environmental protection expenditures made by firms. These data show how businesses allocate compliance costs across purchases of emission control equipment and other necessary inputs (as detailed in Chapter 5). By tracking these purchases, EMPAX-CGE is able to move beyond a generic application of "costs" and consider how these expenditures affect other parts of the economy in a general equilibrium setting.

Along with the energy data, production nesting structures, and elasticities designed to portray behavioral responses to environmental policies, EMPAX-CGE can be used in conjunction with energy-sector models such as the Integrated Planning Model (IPM). IPM is a detailed model of electricity generation and transmission used by EPA to investigate various electricity policies.[4] It provides results on electricity prices, fuel use, and generation costs to EMPAX-CGE for policies where it is important to reflect disaggregated unit-level results that cannot be readily modeled in a CGE model (as detailed in Appendix B).

[4]See http://www.epa.gov/cleanair2004/ for recent IPM analyses of air pollution regulations.

To evaluate policy implications, EMPAX-CGE provides results for an extensive list of macroeconomic variables at the regional level, including the following (among others):

- welfare (standard of living)
- gross domestic product (GDP)
- energy prices
- fuel use by firms and households
- prices and output of commodities
- employment and wage rates
- capital earnings
- exports and imports

CHAPTER 3
EMPAX-CGE MODELING FRAMEWORK

Three components of a CGE model influence estimated policy effects:

1) the model nesting structure controls which types of inputs can be substituted for each other in production and consumption,

2) the elasticities determine the ease with which these substitutions can be made, and

3) the baseline dataset describes the economy prior to implementation of a new policy.

This chapter discusses the derivation of the nesting structure and elasticities and how they are specified in EMPAX-CGE, while Chapter 4 presents the data sources used by EMPAX-CGE.

In EMPAX-CGE, the nesting structure and elasticities are generally based on MIT's CGE model called the Emissions Prediction and Policy Analysis Model, or EPPA, as described in Babiker et al. (2001).[1] Although the applications of the two models are quite different (EPPA is an international model with a single region for the United States that is mainly used to examine global climate change policies), both are intended to estimate how producers and consumers will respond to energy/environmental policies. Given this basic similarity in the objectives of the two models, EMPAX-CGE has adopted a comparable structure.[2]

3.1 Production

Following the Arrow-Debreu general equilibrium structure, firms are assumed to be perfectly competitive (i.e., they are price takers and are unable to influence market prices). Their production technologies exhibit constant returns to scale with the exceptions of agriculture and

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[1]See http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt71.pdf for documentation of the EPPA model. A number of changes have been made to EPPA since publication of this document, but we do not have enough information to include these updates in EMPAX-CGE.

[2]EPPA and EMPAX-CGE also differ in their handling of dynamics, capital stocks, and natural resources. The static version of EMPAX-CGE models long-run responses to policies but does not attempt to examine the transition path an economy takes to reach a new long-run equilibrium. The dynamic version of EMPAX-CGE is an intertemporally optimizing model that assumes agents can respond in the present to expected future policies, while EPPA is a recursive dynamic model that assumes agents do not react until a policy is actually instituted. Capital stock adjustments associated with dynamics are treated in different ways as well: EMPAX-CGE uses capital adjustment costs (see Section 6.4), while EPPA separates capital into "malleable" and "rigid" components and tracks how industry-specific nonmalleable stocks depreciate over time. Handling of natural resources is also somewhat different between the two models: EPPA sets resource prices to forecasts through 2010 and then allows prices to be determined by resource availability and supply elasticities since EPPA models climate policies through 2100. EMPAX-CGE relies on resource price forecasts through 2025 instead of modeling specific resource availabilities (see Section 6.3).

natural resource sectors that have decreasing returns to scale because of use of factors in fixed supply (land and inputs of primary fuels, respectively). These assumptions interact with the three features listed above when examining policies.

This chapter presents the elasticity values and complete CES nesting structures for firms and households in EMPAX-CGE, as noted above. These features are largely based on MIT's EPPA model. However, the underlying dataset and other parts of EMPAX-CGE are not shared with EPPA (as noted). The elasticity values shown in Tables 3-1 through 3-4 were derived by MIT from Burniaux, Nicoletti, and Oliveira-Martins (1992), Nainar (1989), Nguyen (1987), Pindyck (1979), and expert advice. The nesting structures of the CES functions are based on expert advice received by MIT and are designed to reflect input substitution possibilities from "bottom-up" engineering models.

Table 3-1 shows elasticity values used in EMPAX-CGE by most manufacturing and service industries, and the following diagrams illustrate how substitution possibilities are characterized. In the diagrams used to illustrate production and consumption functions below, straight lines are used to show which types of inputs can be substituted for each other, according to which inputs are listed at the end of each straight line. The ease with which substitutions can be made is indicated by the elasticity of substitution (σ) at the end of the curved lines. Inputs shown at the end of the lines are combined together to form a composite good at the next higher level in the diagram using these CES elasticities.

Table 3-1. General Production Elasticities

Variable	Variable Type	Value	Application
σ_{mat}	Elasticity of substitution among material inputs	0	All sectors (includes inputs of goods to production, not factors or energy)
σ_{eva}	Elasticity of substitution between energy and value added	0.5	All sectors except electricity
		0.4	Electricity
σ_{va}	Elasticity of substitution between labor and capital	1.0	All sectors
σ_{enoe}	Elasticity of substitution between electric and nonelectric energy	0.5	All sectors

Source: Babiker, M.H., J.M. Reilly, M. Mayer, R.S. Eckaus, I.S. Wing, and R.C. Hyman. 2001. "The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results." MIT Joint Program on the Science and Policy of Global Change, Report No. 71. Cambridge, MA.

Figure 3-1 illustrates the general production structure used by most industries in EMPAX-CGE. The only industries not using this structure are:

1) the natural resource sectors (coal, crude oil, and natural gas),

2) petroleum refining, and

3) agriculture.

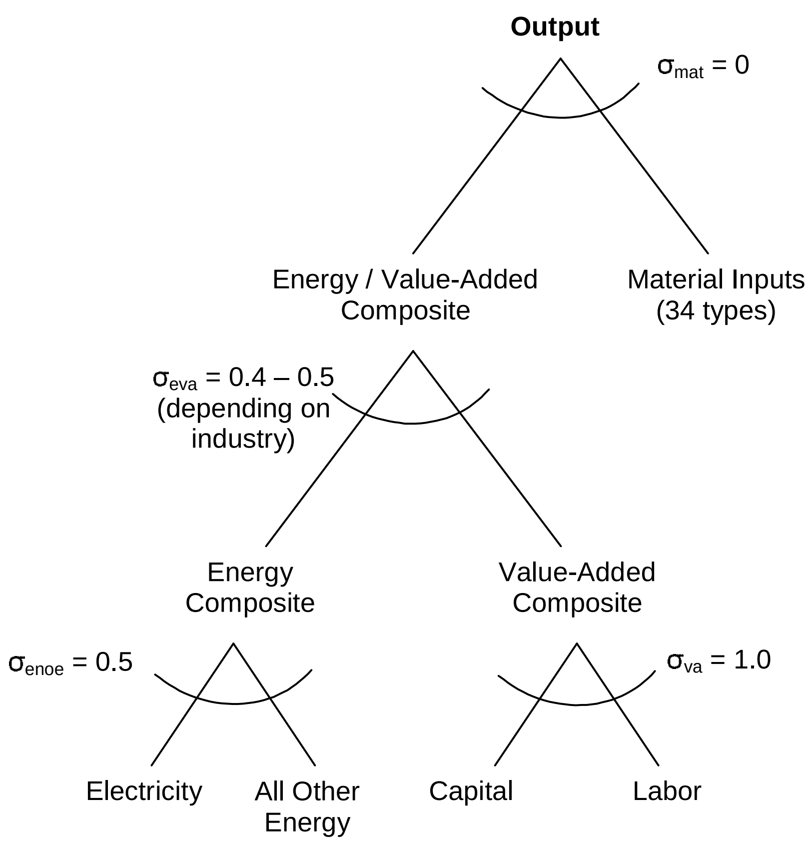

Figure 3-1. General Production Structure

Some differences among industries also exist in the manner by which types of energy can be substituted for each other to form the "energy composite" good shown in Figure 3-1 (these assumptions are highlighted in Figures 3-2 and 3-4).

Materials Inputs

Materials are combined with an energy/value-added composite good that covers all capital, labor, and energy use by firms. The ability to substitute between value-added and energy varies slightly across industries (σ_{eva}). The lower value for electricity reflects the fact that energy is an essential input to generation and substitution possibilities are more limited than for other industries.

The inputs of “materials” in Figure 3-1 cover all intermediate inputs other than energy, factors of production (capital and labor), and natural resources. Materials enter production using a Leontief structure (i.e., fixed coefficients in production). The implication of Leontief technology is that producers (households) can adjust their energy consumption by changing total output (consumption), substituting one type of energy for another, or using additional labor or capital to achieve energy-efficiency improvements. Intermediate materials inputs are Armington goods—meaning that, prior to being used in production, domestic and imported goods are combined to produce composite “Armington” goods that are used by firms.

Energy/Value-Added Composite

Following standard modeling conventions, EMPAX-CGE assumes that capital and labor are combined using a Cobb-Douglas function (σ_{va} equal to 1) to form the value-added composite good. Value added is combined with the energy composite, which is made up of all available types of energy. Within the energy composite, another elasticity, σ_{enoe}, controls the ability of firms to shift between electricity and other types of energy.

There are some differences across industries in how the “energy” composite is formed from various energy inputs. These differences are detailed in the next section and illustrated in Figures 3-2 through 3-4.

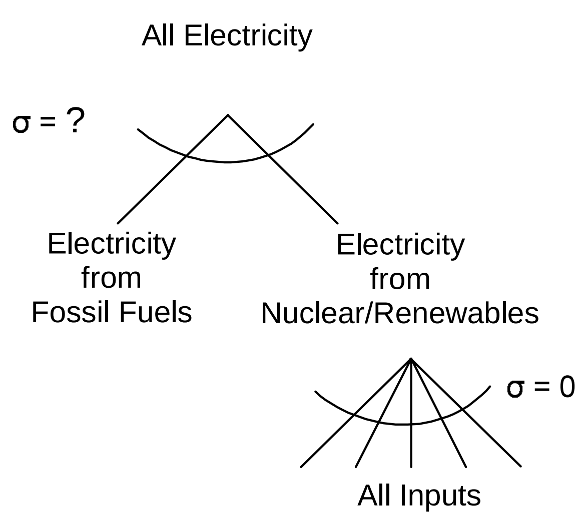

Figure 3-2. Electricity Generation

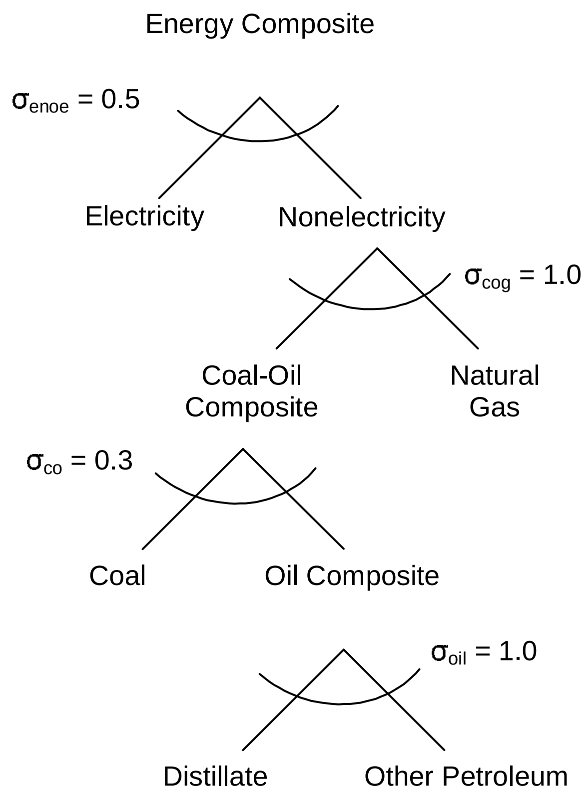

Figure 3-3. Energy Use in Fossil-Fueled Electricity Generation[3]

3.1.1 Electricity Generation

The CGE model formulation used to represent electricity generation will have important effects on the results of environmental policies investigated by EMPAX-CGE. Electricity generation is unique from most other types of production in that it depends critically on energy inputs to create its output. There are also established theoretical and engineering bounds on how efficiently generators can convert fossil energy into electricity, which must be taken into consideration when designing the model. As the result of these considerations, the CES nesting structure used for electricity generation is different than those used for other industries.

As illustrated by the technology structure in Figure 3-2, electricity in EMPAX-CGE can be generated either by the fossil-fuel nest discussed above or by nonfossil sources. The two types of generation are separated so that EMPAX-CGE can track heat rates in fossil generation

[3]Note: Since publication of the EPPA documentation (Babiker et al., 2001) that describes this electricity generation structure, EPPA has switched to modeling several types of electricity generation in separate production structures, but we do not have enough information on the details to adopt a comparable approach in EMPAX-CGE.

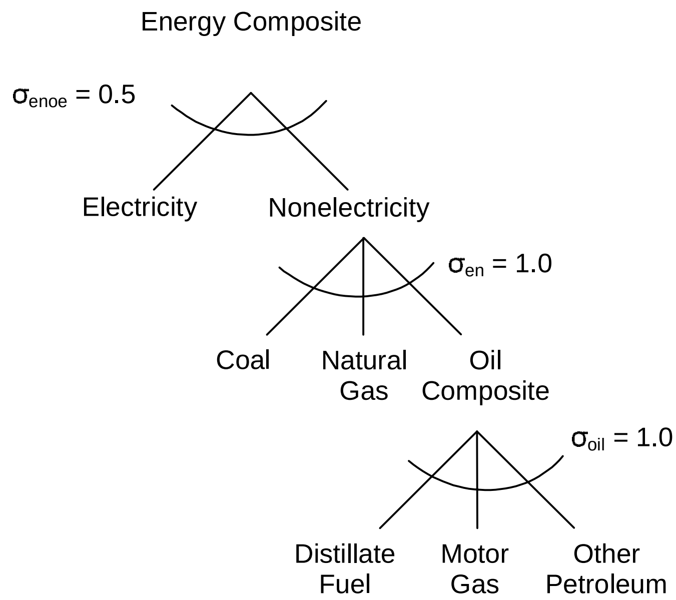

Figure 3-4. Energy Use in Manufacturing, Nonmanufacturing, and Service Sectors

(BTUs of energy input per kWh of electricity output) to ensure that fuel use per unit of electricity is consistent with theoretical limits and available technologies. There is an infinite elasticity of substitution at the top of the CES nest that combines electricity from the two sources, indicating that no distinction is made between electricity produced from these two methods. Table 3-2 shows several elasticities related to energy inputs, some of which are used exclusively by the electricity sector and others that are occasionally applied to other industries as well.

Table 3-2. Elasticities Related to Energy Use in Electricity and Manufacturing/Services

Variable	Variable Type	Value	Application
σ_{cog}	Elasticity of substitution between gas and coal-oil in fossil generation	1.0	Electricity only
σ_{co}	Elasticity of substitution between coal and oil in fossil generation	0.3	Electricity only
σ_{oil}	Elasticity of substitution among types of petroleum (distillate, motor gasoline, and other petroleum)	1.0	All sectors and households
σ_{en}	Elasticity of substitution between nonelectric energy sources	1.0	All sectors except electricity

Source: Babiker et al. (2001), except for σ_{oil} (assumed to be Cobb-Douglas).

Fossil-Fuel Electricity Generation

As shown in Figure 3-3, the nesting structure by which fossil fuels can be substituted for each other is unique for electricity generation. The most important trade-off is between coal and natural gas because these are the two main fossil-fuel options available to utilities, and many environmental policies of interest are likely to cause a shift between these fuels. Although use of distillate and other petroleum in generation is included in EMPAX-CGE,[4] the share of oil in total fuel use is quite small and will not have as much influence on results as coal and natural gas. In EMPAX-CGE, natural gas is combined with a coal-oil composite (σ_{cog}) using a Cobb-Douglas formulation. Following that, coal is combined with oil (σ_{co}), where the oil composite is made up of distillate and other types of petroleum (composed primarily of residual fuel in the electricity generation sector).

Nuclear/Renewable Electricity Generation

EMPAX-CGE currently assumes that the amount of nuclear and renewable generation will not be affected by the policies being investigated.[5] Consequently, this generation is fixed at the levels given in the EIA's Annual Energy Outlook forecasts. The implications are that policies investigated by EMPAX-CGE will not have large enough cost impacts to overcome existing cost differentials between fossil and renewable generation and additional nuclear units will not be built as the result of the policies. Data from the EPPA model showing the ratios of inputs in nuclear and coal generation have been used to characterize inputs to EMPAX-CGE's nonfossil generation. Use of these data gives nuclear/renewable generation a higher capital-labor ratio than fossil generation, which reflects the general cost structure of the two technologies.

3.1.2 Manufacturing, Nonmanufacturing, and Services

Manufacturing, nonmanufacturing, and services (including transportation services) use the general production nesting structure shown in Figure 3-1; however, the energy-value added elasticity (σ_{eva}) is higher than for electricity. This higher elasticity indicates that it is relatively easier to achieve energy efficiency improvements in manufacturing than in the electricity sector, which relies heavily on energy for generation purposes.

Some differences between these industries and the electricity sector exist in the substitution possibilities among energy types. Figure 3-4 shows how the energy composite good is formed for industrial and service sectors. The nesting structure draws fewer distinctions

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[4]The EPPA model includes oil generation but does not distinguish among types of petroleum. Similarly, the dynamic version of EMPAX-CGE only considers one type of refined petroleum.

[5]In contrast, because of its focus on long-run climate policies that can cause dramatic shifts in generation technologies, the EPPA model allows for some limited substitution in nuclear generation between value-added (i.e., capital and labor) and nuclear resources and also permits building of new carbon-free (i.e., renewable) generation at a substantial cost markup over other forms of generation.

among types of energy than in electricity generation because the main trade-offs in nonelectricity industries are between natural gas and refined petroleum, rather than between coal and natural gas (electricity generation consumes around 90 percent of all coal used in the United States, and coal is a much less important energy source for other parts of the economy).

3.1.3 Fixed Resource Sectors (Agriculture and Fossil Fuels)

The CES nesting structures used for agriculture and natural resource industries are designed to reflect the presence of a factor of production that is available in fixed, or limited, supply. In the case of agriculture, this fixed factor is land. Similarly, production of fossil fuels relies on inputs of natural resources that are available in limited supply. Table 3-3 shows the elasticities that are included in the production functions describing these sectors, which are discussed separately below.

Table 3-3. Elasticities Related to Resource Sectors

Variable	Variable Type	Value	Application
σ_{erva}	Elasticity of substitution between energy-resource and valued added	0.6	Agriculture only
σ_{er}	Elasticity of substitution between energy-material bundle and resource	0.6	Agriculture only
σ_{ae}	Elasticity of substitution between materials and energy	0.3	Agriculture only
σ_{gr}	Elasticity of substitution between natural resource input and other inputs to resource production	0.6	Crude oil, coal, and natural gas production
σ_{toil}	Elasticity of transformation in production of petroleum products from crude oil and other inputs	1	Petroleum refining sector

Source: Babiker et al. (2001), except for σ_{toil} (assumed to be Cobb-Douglas).

Agriculture

The agriculture sector is designed to reflect the presence of land in production (see Figure 3-5).[6] In the top nest, value added is substituted against a resource-materials-energy bundle. This substitution maintains a distinction between output per unit of land and output per unit of labor and capital and allows agricultural output to be increased by additions of land (if possible), materials, and energy, or value-added factors of production. This top-level nest (σ_{erva})

[6]EMPAX-CGE assumes that the fixed resource (land) earnings represent one-third of the capital payments shown in the IMPLAN data for the agricultural sector (see Chapter 4 for a discussion of these data).

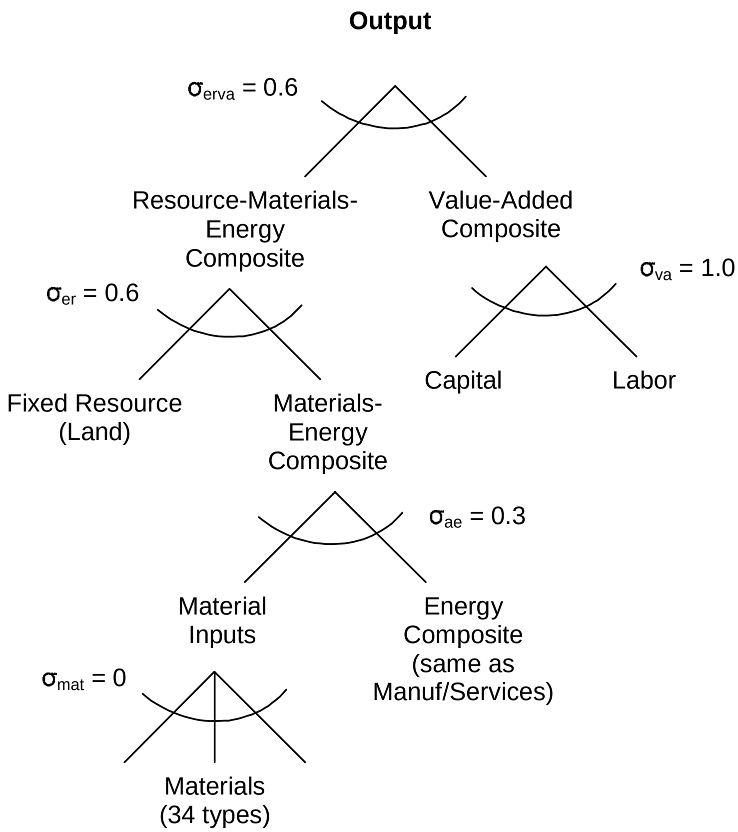

Figure 3-5. Structure of Agricultural Production

allows agricultural efficiency per unit of land to be improved by using additional capital or labor. Energy and materials (σ_{ae}) can be substituted with some difficulty for the fixed land resource (σ_{er}), indicating that land can be made more productive by using materials (e.g., fertilizer) or energy (e.g., heating greenhouses or running farm equipment). Substitutions among energy types to form a composite energy good have the same structure as in manufacturing and services.

Natural Resources

Production of natural resources (coal, crude oil, and natural gas) is handled in a manner similar to agricultural goods (see Figure 3-6). Output of these sectors is limited by the availability of the natural resource, hence, the use of a fixed factor in production to approximate resource constraints and give the production function decreasing returns to scale. This captures the idea that, although it is possible to develop more efficient mining equipment or invest in discovering new mines, it is not possible to produce natural resources using only factors like capital/labor or intermediate inputs. In the production nesting structure, coal in the ground, for example, is combined with other inputs to make it available for use by other industries. Some increase in output is allowed by use of additional factors or materials, but these must be combined (σ_{gr}) with the fixed factor at the top of the nest.

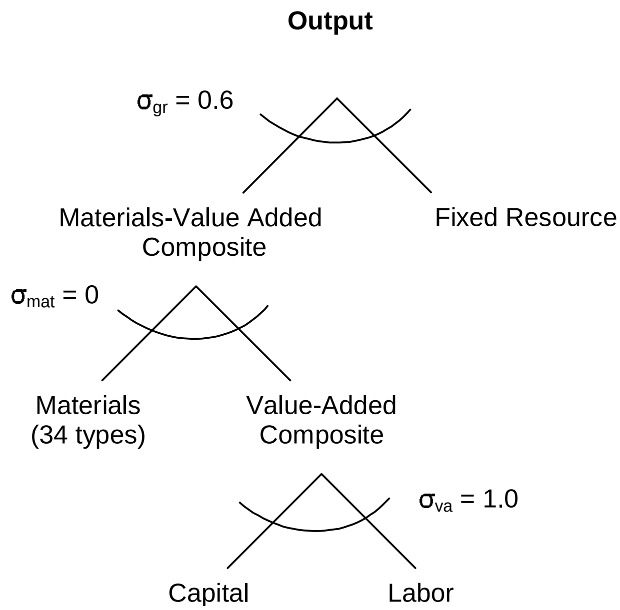

Figure 3-6. Structure of Natural Resources Production (Coal, Crude Oil, Natural Gas)

The values of the rents earned by natural resources are based on MIT data from the EPPA model. For the United States, the shares of total production costs attributed to payments to resource owners are 10 percent for coal, 33 percent for crude oil, and 25 percent for natural gas. It is assumed that these payments are included in capital payments shown in the IMPLAN data[7] and, consequently, EMPAX-CGE separates out resource earnings from the more general payments to capital owners in the economic data.

Petroleum Refining

Petroleum refining is not a natural resource sector. However, its production is similar in that it depends on inputs of crude oil, which cannot be replaced by other types of materials (see Figure 3-7). The elasticity of substitution, σ_{va}, captures the idea that some factor substitution is possible in refining technology. However, crude oil and materials enter the production structure in fixed proportions to ensure it is necessary to use crude oil to produce petroleum products.

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[7]Capital payments are typically calculated as the residual of all other payments and hence would include these resource earnings.

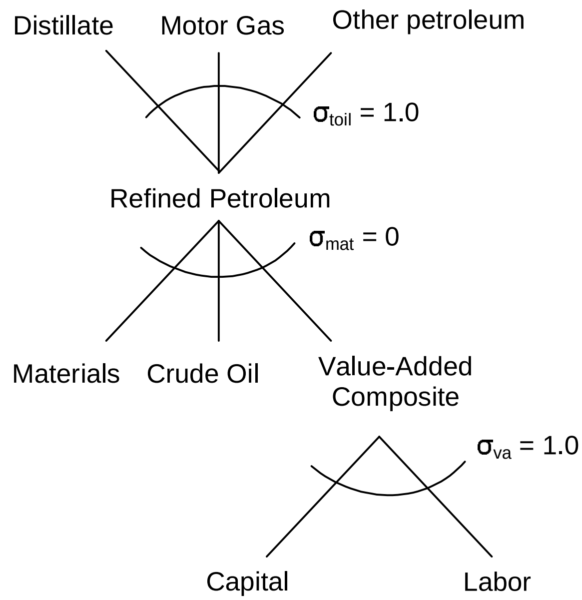

Figure 3-7. Petroleum Refining Structure

EMPAX-CGE tracks three types of petroleum products: distillate fuel, motor gasoline, and "other" petroleum. The elasticity of transformation, σ_{toil}, illustrates that it is possible to convert crude oil into a variety of petroleum products (transformation functions are shown as lines pointing up, rather than down). In the absence of other information, this transformation elasticity is assumed to be Cobb-Douglas, which is the typical default assumption in CGE models.

3.2 Households

EMPAX-CGE has the capability to represent multiple types of households by income class in each region of the country, if it is desired for a particular policy analysis.[8] Environmental policies can influence income distributions and affect households in substantially different ways, depending on their consumption patterns and income sources. By including several types of households classified by income, EMPAX-CGE is able to provide additional information on how environmental policies affect different groups of consumers across regions of the nation.

The IMPLAN economic database used by EMPAX-CGE distinguishes among nine households classified by income. Their expenditure patterns and income sources have been

[8]Prior to running the model, the number of households to be included can be specified from the nine income classes defined by the IMPLAN data.

developed from the U.S. Bureau of Labor Statistics' *Consumer Expenditure Survey* and the U.S. Census Bureau's *Decennial Census and Population Surveys*. These nine consumer groups cover households in the following annual income classes:

- $0 to $4,999
- $5,000 to $9,999
- $10,000 to $14,999
- $15,000 to $19,999
- $20,000 to $29,999
- $30,000 to $39,999
- $40,000 to $49,999
- $50,000 to $69,999
- $70,000 and above

The two static versions of EMPAX-CGE can include all nine types of households simultaneously or can aggregate selected groups (or all groups) together for a specific model run. In the dynamic version, computational limitations reduce the number of households that can be incorporated.

For each household included in a model run, EMPAX-CGE uses a nested CES structure to model consumer preferences in each of the 10 regions in EMPAX-CGE (regional static version). As shown in Figure 3-8, all consumption goods are combined using a Cobb-Douglas structure to form an aggregate consumption good. This composite consumption good is then combined with leisure time to produce household utility, or welfare. The elasticity of substitution between consumption goods and leisure (σ_{cl}) indicates how willing households are to trade off leisure time for consumption.[9] Consequently, it controls how consumers will respond to changes in good prices and changes in wage rates. Table 3-4 shows the elasticities related to household consumption and to traded goods, which are combined using the Armington assumption to form these consumption goods.

The representative household(s) in each region is endowed with factors of production including labor, capital, natural resources, and land inputs to agricultural production. 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 are allocated to purchases of consumption goods to maximize welfare.

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[9]See Chapter 7 for a discussion of how this elasticity is determined.

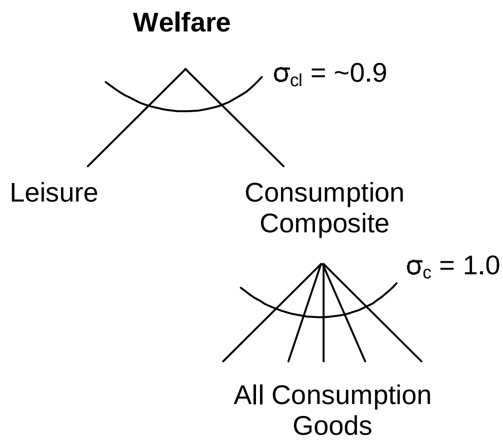

Figure 3-8. Household Utility Function

Table 3-4. Elasticities Related to Household Consumption and Trade

Variable	Variable Type	Value	Application
σ_{cl}	Elasticity of substitution between consumption and leisure	~0.9	Household trade-off between consumption and leisure
σ_c	Elasticity of substitution among consumption goods	1	All goods consumed by households
σ_{dm}	Armington elasticity of substitution between domestic and imported goods	3	All sectors except electricity (0.3)
σ_{mm}	Armington elasticity of substitution among imports	5	Nonenergy goods
		4	Energy goods except crude oil (homogeneous good => infinite elasticity) and electricity (0.5)
σ_t	Elasticity of transformation between goods for domestic consumption and exports	2	All sectors

Source: Babiker et al. (2001), except σ_{cl}. and σ_t. See Section 7.4 for derivation of consumption-leisure elasticities, which were not included in the 2001 version of the EPPA model (they have been added for the tax analysis in Babiker, Metcalf, and Reilly [2002]).

The structure of household utility in EMPAX-CGE allows measurement of welfare changes from a policy in a convenient manner. Welfare changes capture a wide variety of effects that influence how consumers are affected by a policy, including changes in income, changes in the costs of consumption goods, and changes in work effort. The method for measuring welfare normally used by economists involves calculating Hicksian equivalent variation. This is the amount of income that would be needed to compensate households for economic effects of a policy. Because EMPAX-CGE includes a utility function, it is able to estimate this variable, instead of merely calculating income effects of policies or GDP changes, which ignore important consequences of policies for consumers.

Savings are not included in consumers' utility functions in the static version of EMPAX-CGE because it is not attempting to model adjustment dynamics over time (savings do not usually play a role in static models).[10] In the dynamic version of EMPAX-CGE (as detailed in Chapter 6), savings provide the basis for capital formation and are motivated through people's expectations about future needs for capital.

3.3 Trade

Regions constructed in CGE models are often assumed to be small, open economies that are unable to influence import and export prices. In this case, pure trade theory suggests that each region would produce and export only those goods in which it has a comparative advantage and import all other tradable goods. However, empirical trade data routinely reveal "cross-hauling," which is the simultaneous import and export of the same type of goods. CGE models typically try to avoid the "all or nothing" specialization effects that trade theory implies because it is not consistent with empirical data and can exaggerate the effects of policies. The majority of multiregion CGE models represent trade among regions employing an assumption that goods produced in different regions are imperfect substitutes for one another (i.e., Armington good represented by CES functions).

In EMPAX-CGE, goods and services consumed by households (and the intermediate materials used by firms) are composite goods made up of locally manufactured commodities, commodities from other regions in the United States., and foreign (non-U.S.) goods. This Armington formulation is illustrated in Figure 3-9. At the bottom of this nesting structure, output of local industries is differentiated into output destined for local consumption by producers or households and output destined for exports using a CES transformation elasticity, σ_t. Following the model's Armington structure, local output and regional imports are then combined using a relatively high elasticity, which indicates that agents make relatively little distinction between output from firms located within their region and output from firms in other regions within the United States. This domestic composite good is finally aggregated with imports from foreign sources using a lower elasticity to capture the fact that foreign imports are more differentiated from domestic output than are imports from other regional suppliers in the country.[11]

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[10]Note: This assumption about the role of savings in the utility function is different than that utilized in the MIT EPPA model. Since EPPA is a recursive dynamic model, it assumes that savings provide utility to households in order to motivate savings for future time periods.

[11]Crude oil is modeled as a homogeneous good that is identical across all regions, rather than through an Armington structure.

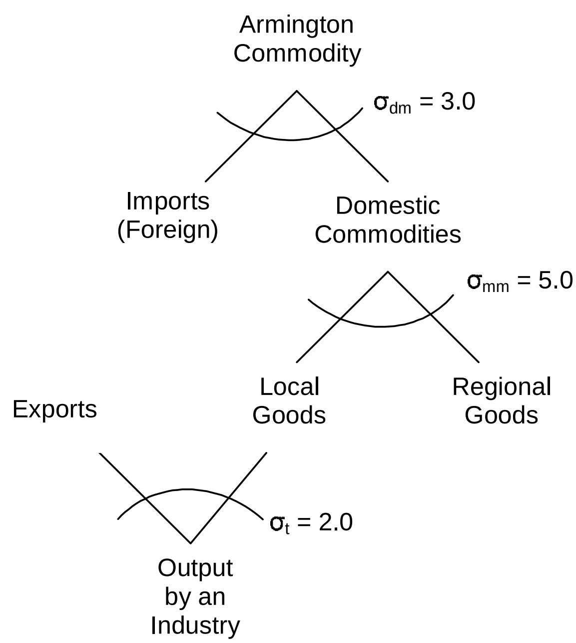

Figure 3-9. Trade Functions

EMPAX-CGE assumes that any trade deficits or surpluses indicated by the original data are maintained during policy simulations in the model. It is also assumed that ownership of natural resources and the capital embodied in nuclear/renewable electricity generation are spread across the country, based on each region's share of total national income. Sharing out ownership across regions tends to smooth out welfare changes as the income impacts of policies are spread more broadly across households in the United States. Impacts on industrial output and energy use from assuming broad ownership of factors and resources is much less substantial because these are most directly affected by production costs and energy prices.

Following standard conventions used in general equilibrium models, factors of production are intersectorally mobile within regions, but trade in productive factors is not allowed among regions of the United States or with foreign agents. This assumption is necessary to calculate welfare changes for representative households in each of the 10 regions in EMPAX-CGE. It is also currently assumed that policies investigated by EMPAX-CGE do not influence world prices of goods.[12]

3.4 Government and Investment

Government purchases and investment are exogenous variables in the static version of EMPAX-CGE. Because investment decisions in the static version are not linked to formation of

[12]This assumption could be changed to incorporate foreign export demand and import supply elasticities.

capital for future production, investment purchases are determined from the IMPLAN data and are tracked in EMPAX-CGE, but they do not enter the optimization decisions of households. Government purchases of goods and services are also shown in the economic data and are included in EMPAX-CGE, but they do not adjust in response to policies. Government expenditures are financed by taxes on commodities, income, and capital (as detailed in Chapter 7). This allows EMPAX-CGE to consider how environmental policies may interact with existing taxes and resulting implications for policy costs.

3.5 Market Clearing

All markets for factors and goods must clear simultaneously to find a general equilibrium solution in EMPAX-CGE (i.e., supply must equal demand for all commodities). This market clearance determines equilibrium prices for factors and goods. The model solution occurs at a point where the marginal costs of production are equal to the marginal benefits from an additional unit of output as measured by the prices that firms and households are willing to pay for commodities. Factor prices are equal to the marginal revenue received by firms from employing an additional unit of labor or capital. Values of these factors are determined by demand of firms within each region so there are regional differences in factor prices. An alternative would be to adjust the model so that returns to labor and capital are equalized across the United States, rather than assume regional productivity differences exist. However, given the relatively large variation in economic growth forecasts across regions of the country in the AEO, assuming regional productivity differences will be closer to the forecasts used by EIA to generate the AEO energy consumption statistics.

CHAPTER 4
DATABASE AND CALIBRATION

This chapter discusses the data sources used in EMPAX-CGE and the methodology for integrating the economic and energy data. EMPAX-CGE relies on a wide variety of data sources to provide the data necessary to develop a SAM that characterizes the U.S. economy at a regional level. The SAM combines information on the economy with several types of energy data.

4.1 Social Accounting Matrix

CGE models are typically based on a social accounting matrix (SAM), which is an economy wide dataset that shows how resources flow through the economy at a specific point in time (see Shoven and Whalley [1992]). The framework for these data comes from traditional I/O analyses, originally developed by Leontief (1936). An I/O table represents the value of economic transactions at a particular point in time. As such, it shows how firms combine intermediate inputs and factors of production to produce output. This output is directed towards intermediate and final uses, where intermediate uses are the goods and services employed by other firms to manufacture their output and final uses are the ultimate destination of consumer goods purchased by households and government.

A SAM is an expanded version of the traditional I/O table. Unlike I/O data, a SAM contains information on ownership of factors of production, which allows CGE models to estimate policy effects on the distribution of income. In addition, a SAM contains data on direct taxes that are removed from income received by agents and transferred to the government, and vice versa. I/O tables, which ignore income, typically only include indirect taxes that are levied on purchases of intermediate production inputs or on expenditures for final goods of production. By covering all economic flows among agents, a SAM provides the basis for building a static CGE model or for providing a benchmark dataset for a dynamic CGE model.

Table 4-1 presents an aggregated version of a typical SAM. The table illustrates the circular flow in an economy—demand for goods and services leads to production activities, which generate income that leads back to demand. The "Activities" column shows how intermediate inputs, factors, and taxes paid by producers are combined to produce output. The other columns show how expenditures are made by agents in the model. Rows in the SAM give demands for commodities and income sources for agents. For example, demand for the gross output of a commodity (the "Commodities" row) is divided among intermediate input purchases by enterprises, household consumption, government purchases, use of commodities to make investment goods, and exports. Similarly, income for households comes from sales of factors to

Table 4-1. Basic SAM

	Expenditures							
Receipts	**Activities**	**Commodities**	**Factors**	**Households**	**Government**	**Savings/ Investment**	**Rest of World (ROW)**	**Total**
Activities		Gross output						Gross output
Commodities	Intermediate inputs			Household consumption	Government consumption	Investment	Exports	Demands
Factors	Capital and labor						Factor income from ROW	Factor income
Households			Household income from factor ownership		Government transfers to households		Household transfers to ROW	Household income
Government	Output taxes, factor taxes	Sales taxes, export taxes	Government income from factor ownership/ taxes	Household transfers to government (direct)			ROW transfers to government	Government income
Savings/ Investment				Household savings	Government savings		Foreign savings	Savings
Rest of World (ROW)		Imports	ROW income from factor ownership		Government transfers to ROW			Capital outflows to ROW
Total	Activity	Supply expenditures	Factor expenditures	Household expenditures	Government expenditures	Investment	Capital inflows from ROW	

firms and transfers to households from the government or foreign agents (the "Households" row). This income is used to purchase private consumption goods, for direct transfers to the government, and to save for the future (the "Households" column).

In a balanced SAM, corresponding row and column sums are equal. This means that supply equals demand for all goods and factors, tax payments equal tax receipts, there are no excess profits in production, the value of household expenditures equals the value of factor income plus transfers, and the value of government tax revenue equals the value of transfers.

4.2 IMPLAN Economic Data

Economic data necessary to develop a SAM for EMPAX-CGE are provided by the Minnesota IMPLAN Group (see Table 4-2), and the programs used to read these data were developed by Rutherford (2004). State-level information from IMPLAN shows how goods are manufactured using various intermediate inputs and factors of production. It also shows demands for goods and services by agents such as households and government. In addition, IMPLAN contains information on how these expenditures are financed by households' sales of factors to businesses and by government tax collections.

Table 4-2. EMPAX-CGE Economic Data Sources

Data Source	Data Table	Data Elements
IMPLAN	State-level economic data for year 2000	Output by industry Inputs to industries Consumer purchases and income Exports and imports
Commodity Flow Survey (Bureau of Economic Analysis)	Trade flows in 1997	Interstate trade data by commodity

IMPLAN contains data on production and consumption of 528 different types of commodities for the year 2000. These data have been developed from a variety of federal government sources, including

- U.S. Bureau of Economic Analysis Benchmark I/O Accounts of the United States,
- U.S. Bureau of Economic Analysis Output Estimates,
- U.S. Bureau of Economic Analysis REIS Program,
- U.S. Bureau of Labor Statistics Covered Employment and Wages (ES202) Program,

- U.S. Bureau of Labor Statistics Consumer Expenditure Survey,
- U.S. Census Bureau County Business Patterns,
- U.S. Census Bureau Decennial Census and Population Surveys,
- U.S. Census Bureau Economic Censuses and Surveys,
- U.S. Department of Agriculture Crop and Livestock Statistics, and
- U.S. Geological Survey.

Computational limitations of CGE models and available energy data (discussed below) were considered when determining the size and scope of EMPAX-CGE. As a result of these factors, the 528 sectors in IMPLAN have been aggregated into the industries in EMPAX-CGE. These industries have been selected based on their relevance to the types of energy/environmental policies that EMPAX-CGE has been designed to investigate, in conjunction with the availability of complete energy and economic data.

Although IMPLAN provides exports and imports of goods and services for each state, the data do not include information on the nature of interregional trade flows. To determine the origin of a state's imports and the destination of a state's exports, the IMPLAN data are combined with the Commodity Flow Survey conducted by the Bureau of Economic Analysis at the Department of Commerce. The Survey shows the origin and destination of each state's trade flows of goods and services. These statistics are used to apportion IMPLAN's general export and import data into state-to-state trade data. Once the economic data have been aggregated into the sectors used in EMPAX-CGE and trade flows have been established, the state-level data are aggregated into the regions used in EMPAX-CGE.

4.3 Energy Data Sources

The IMPLAN economic data are supplemented by additional data sources on energy production and consumption for two reasons: (1) because the policies being investigated by EMPAX-CGE focus on energy markets, it is essential to have the best possible characterization of these markets in the model, and (2) EMPAX-CGE uses a baseline starting year that is different from the year-2000 data provided by IMPLAN (discussed in Section 4.5 on data integration).

Although IMPLAN relies on government information when creating their datasets, the focus of IMPLAN is not energy/environmental policies. This leads, in some instances, to differences between the IMPLAN economic data and the energy data collected by the Energy Information Administration at the Department of Energy. Where these differences occur, EMPAX-CGE is based on EIA data. These sources are shown in Table 4-3, which lists the data source and specific table of data used and gives a description of the tables.

Information on energy production at the state level comes from EIA's annual industry profiles that collect data on coal, electricity, natural gas, and petroleum production. Energy consumption data in EMPAX-CGE are based on the Manufacturing Energy Consumption Survey (MECS) produced by EIA and historical data from EIA's AEO, which shows industry-level consumption of different types of energy. The Commercial Buildings Energy Consumption Survey by EIA is also used to supplement energy consumption information from the MECS.

In addition, because EMPAX-CGE is used to investigate the effects of policies in the future, it requires a dataset that reflects changes that are expected to occur in energy markets in the absence of the policies under investigation. For this reason, EMPAX-CGE incorporates the forecasts from the AEO into its baseline dataset.

4.4 Energy Data Calibration

To integrate the EIA energy data and the IMPLAN economic data, it is necessary to have state-level energy data to combine with the economic data. The starting point for this process is the national-level (or, in the case of electricity, NERC-level) energy forecasts in the AEO. These forecasts are combined with the state-level historical data sources shown in Table 4-3 to produce state-level energy consumption, production, and trade forecasts. The following steps are necessary to accomplish this integration (while retaining overall energy market forecasts at the levels given in AEO):

1. Estimate how energy use by five broad categories in the AEO national forecasts corresponds to the wider array of activities in EMPAX-CGE.
2. Determine national-level forecasts for energy consumption, production, and trade.
3. Use EIA state-level energy data to share out the national AEO forecasts to states.
4. Aggregate state-level data into EMPAX-CGE regions and balance interregional energy trade flows.

4.4.1 Step 1: Estimate Energy Use for EMPAX-CGE Sectors

The AEO forecasts of energy consumption in quantity and price terms (Tables 2 and 3, respectively) are given for five broad categories: Residential, Commercial, Industrial, Transportation, and Electricity Generation. For two of these categories, Industrial and Transportation, AEO provides additional details on the parts of the economy that comprise the broader sectors. Energy use in Electricity Generation is available at the NERC-region level in separate tables (Tables 60 through 72). The remaining two categories, Residential and Commercial, distinguish energy use by type of equipment, but not in a fashion that is consistent with industries in EMPAX-CGE.

Table 4-3. EMPAX-CGE Energy Data Sources

Data Source	Data Table	Data Elements
Annual Energy Outlook (EIA)—Historical and forecast data (2000–2025)	Table 1	Total Production, Imports, and Exports (& some Prices) by Fuel
	Table 2	Consumption by Sector and Fuel (Quad Btu)
	Table 3	Prices by Sector and Fuel ($/MMBtu)
	Table 16	Coal supply, disposition, and prices
	Table 20	Macroeconomic variables
	Tables 23-32	Components of AEO Industrial Sector (output, fuel use)
	Table 34	Transportation energy use by use and type of fuel (Quad Btu)
	Tables 60-72	Electricity generation, fuel consumption, and trade by NERC region
State Energy Data Report, 1999 (EIA)	State-level energy consumption data (historic)	Energy consumption data by state, 1999 Categories—residential, industrial, commercial, transportation, electric utilities (physical units and Btus)
State Energy Price and Expenditure Report, 1999 (EIA)	State-level energy consumption data (historic)	Energy consumption data by state, 1999 Categories—residential, industrial, commercial, transportation, electric utilities (Dollars and $/MMBtu)
Coal Industry Annual 2000 (EIA)	Table 10	Coal production by state and coal rank (tons)
	Table 65	Coal trade from state to state (tons)
	Table 85	Coal price (mine mouth) by state and coal rank (tons)
Electricity Power Annual 2000 (EIA)	Table A7	Generation by state (MkWh)
Natural Gas Annual 2000 (EIA)	Table 6	Wellhead value and marketed production (MMCF and dollars)
	Table 12	Interstate and foreign trade by state (MMCF)
Petroleum Supply Annual 2000 (EIA)	Table 14	Crude oil production by PADD and state (barrels)
	Table 20	Imports of crude oil and petroleum from foreign sources (barrels)
	Table 32	Crude oil and refined petroleum trade between PADDs (barrels)
	Table 36	Refinery capacity by state
Manufacturing Energy Consumption Survey, 1998 (EIA)	Table N1.2—First Use of Energy for All Purposes	Industrial energy use by NAICS code and type of fuel (trillion Btu)
Commercial Buildings Energy Consumption Survey, 1995 (EIA)	Table 1. Total Energy Consumption Major Fuel	Energy use by Government-owned and nongovernment buildings (Btu)
Natural Gas Transportation—Infrastructure Issues and Operations Trends (EIA)	Table 1. Interregional Pipeline Capacity and Average Daily Flows, 1990 and 2000	Gas flows among regions of U.S. (MMCF)

The Residential sector in AEO gives household energy use but only includes energy consumption for household appliances, heating, etc. To find total household energy consumption that corresponds with the households in EMPAX-CGE, it is necessary to include energy use for private transportation. This information comes from AEO Table 34, which gives petroleum use by type of vehicle. Motor gasoline use by light-duty, noncommercial, vehicles is assigned to household consumption in EMPAX-CGE.

The Commercial sector in AEO contains energy data on service-providing facilities and equipment. This corresponds to the service sector in EMPAX-CGE, because energy use by industrial facilities is included in AEO's industrial sector. One exception is that government buildings are included in the commercial sector. The most recent Commercial Buildings Energy Consumption Survey (1995) by EIA is used to separate energy consumption by the commercial sector into public and private consumption.[1]

The Industrial sector in AEO covers energy use by manufacturing facilities. Separate forecasts are available for a variety of energy-intensive industries and other sectors such as agriculture and mining (Tables 24 through 32).[2] Other industries such as fabricated metal products, machinery, and equipment (NAICS 332-336) that are separate sectors in EMPAX-CGE have been aggregated into a single "Metals-Based Durables" category in the AEO forecasts. For those industries that have a direct correspondence between AEO and EMPAX-CGE, the individual energy consumption forecasts from AEO have been used. For other industries in AEO like "Metals-Based Durables" that cover several sectors in EMPAX-CGE, information on industrial energy consumption from the MECS is used to share out the broader AEO category into individual industries.

The Transportation sector in AEO covers all energy use by vehicles whose primary purpose is moving people and goods from one location to another. After assigning household and military fuel use to the appropriate sectors in EMPAX-CGE, the remaining energy consumption shown in Table 34 is separated into five modes of transportation: air, freight trucks, railroad, water, and other transportation. This fuel use is assigned to the same categories in EMPAX-CGE.

4.4.2 Step 2: Determine National Energy Forecasts

After energy consumption forecasts are assigned to sectors in EMPAX-CGE, the next step is to determine national-level forecasts for production, exports, and imports that balance

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[1]Military fuel use from Table 34 on the Transportation sector is also assigned to the Government sector in EMPAX-CGE.

[2]See pg. 39 of EIA's publication "Assumptions to AEO 2003." <http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2003).pdf> for the list of industries.

energy markets for each type of fuel in both physical units and value terms (price times quantity). This is done using the accounting identity:

U.S. Production = U.S. Consumption plus Exports minus Imports.[3]

Consumption has been determined by the steps taken above. Exports and imports of energy are given in the AEO forecasts. This leaves production as the residual component of the equation that balances supply and demand.

4.4.3 Step 3: Allocate National Energy Data to States

Once national forecasts are determined for each sector and type of fuel in EMPAX-CGE, it is necessary to determine how to share out the national totals for production, consumption, and foreign and domestic trade to states. The various energy-industry annual publications shown above in Table 8 give state-level production in quantity and price terms, which are used to share out national production data.[4] Energy consumption by sector at the state level comes from EIA publications State Energy Data Report and State Energy Price and Expenditure Report. Consumption data are shared out to states based on both expenditures in dollars and energy use in Btus to maintain differences in energy prices across states. Foreign and domestic energy trade data also come from these industry annuals where available and are proxied where not available.

Coal trade data among states are the most complete of the energy trade data series and can be used without approximations. Although the Natural Gas Annual reports flows among states, it only gives figures for all gas that moves across borders, rather than an initial origin and final destination of the gas. For this reason, gas flows from EIA's "Natural Gas Transportation—Infrastructure Issues and Operations Trends" are used. In the absence of other data, petroleum trade is shared out to states based on state production levels. Electricity trade is available at the NERC-region level in Tables 60 through 72 of the AEO so those levels are used after the state-level data have been aggregated.

4.4.4 Step 4: Aggregate State-level Data to Regions and Balance Trade Flows

Upon determining state-level energy forecasts, the energy data are aggregated into EMPAX-CGE regions, and interregional trade flows are balanced. Once this is done, the energy data are ready to be integrated with the economic data.

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[3]In the case of crude oil, available data (Table 1 in AEO) are for production and trade. Because all crude oil is consumed by the petroleum refining sector to produce different types of refined petroleum, the identity is reversed: consumption = production + net imports.

[4]The exception to this is the Petroleum Supply Annual, which only gives refinery capacity by state, rather than production. In the absence of production data, refinery capacity is used as a proxy for production at the state level.

4.5 Data Integration in the SAM

Integrating the energy data with the economic data to produce a balanced SAM requires the following three steps:

1. Estimating future economic activity starting from the historical IMPLAN data.
2. Combining the economic and energy data.
3. Generating a balanced SAM with interregional and foreign trade flows.

Although the process of calibrating the energy data produces balanced energy markets for each year in the AEO forecast (2000–2025), the IMPLAN economic data are for the year 2000. Therefore, before the data can be integrated with the energy data, they must be projected forward to the baseline year used by EMPAX-CGE. The AEO forecasts provide economic projections for industrial output and macroeconomic variables like GDP and consumption (Tables 23 and 20, respectively). Industrial output forecasts are used to grow the manufacturing sectors in EMPAX-CGE out to the baseline year. Other sectors in EMPAX-CGE like services are assumed to grow at AEO's GDP growth forecast in the absence of other information. Consumption, government, and trade are assumed to expand at the rates given in AEO's macroeconomic forecast (Table 20).

As discussed in Section 4.3, the IMPLAN data do not always adequately represent energy markets because they are not based on data sources such as those used to develop energy statistics for EMPAX-CGE. Consequently, the two types of data (economic and energy) must be integrated after they have been collected. EMPAX-CGE uses a procedure developed by Babiker and Rutherford (1997) and described in Rutherford and Paltsev (2000) to combine these data. This procedure was originally applied to data gathered by the Global Trade Analysis Project (GTAP) at Purdue University and used by many CGE modelers to investigate international energy policies such as climate change.

The methodology involves preserving the energy data and adjusting the economic data to integrate the two datasets. As done in the GTAP project, standard optimization techniques are used to maintain the calculated energy statistics while minimizing the changes necessary to combine them with the economic data. Once the data are integrated, a balanced SAM is generated that matches AEO forecasts for GDP, output, consumption, investment, and government spending.

CHAPTER 5
MODEL CALIBRATION AND POLICY EVALUATION

To use a CGE model to evaluate policies, the various components discussed in Chapters 2 through 4 on functional forms and data must be integrated together, the model must be checked for errors, and the analyst must ensure that the economy is initially in equilibrium. Figure 5-1 summarizes these "calibration" steps as they apply to the development of EMPAX-CGE (and other CGE models). Once data, functional forms, and elasticity values have been calibrated to a "baseline" equilibrium that represents expected economic growth in the absence of new policies, the CGE model is ready to evaluate "counterfactual" policies that move the economy away from the initial equilibrium. The effects of these policies can be appraised by comparing the baseline economy to the counterfactual solution. This chapter discusses the steps involved in model calibration and describes how the model can be used to evaluate environmental policies, including factors that it considers when estimating policy results.

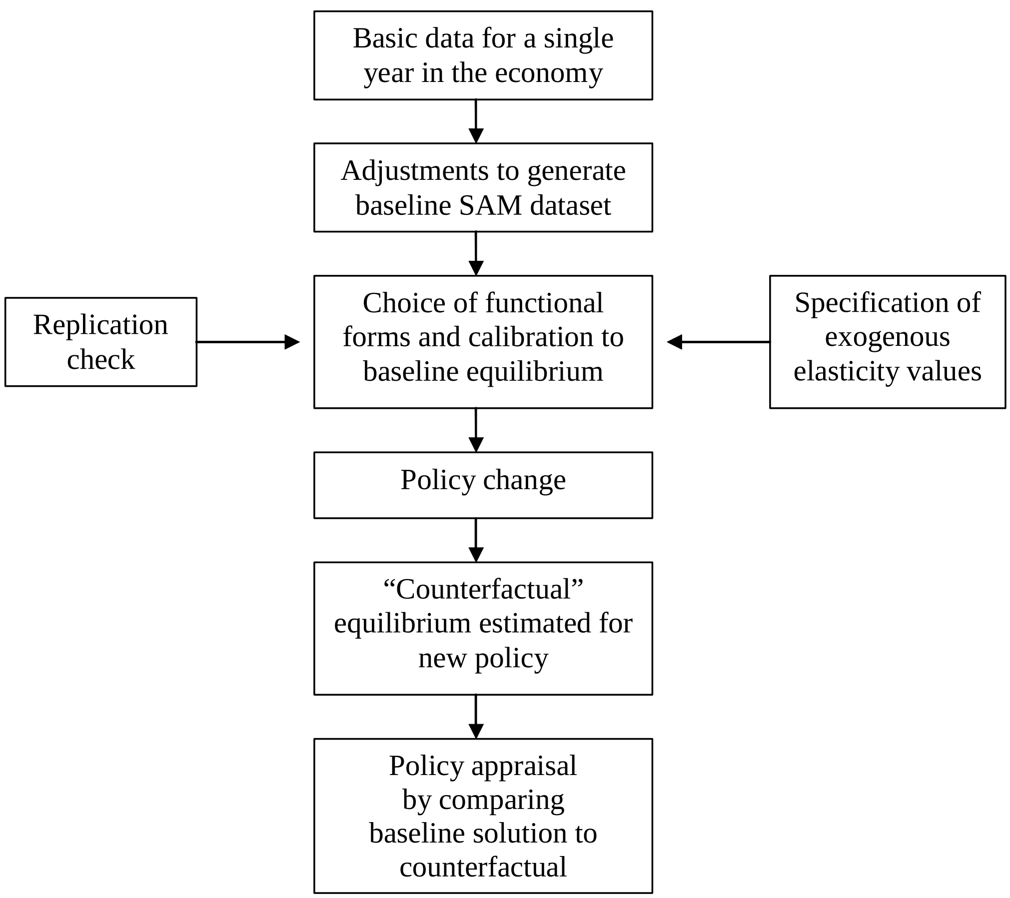

Figure 5-1. Flow Chart of Steps in Developing and Applying a CGE Model[a]

[a]This chart is adapted from Shoven and Whalley's (1992) flow diagram of a typical CGE model.

5.1 Model Calibration

As shown at the top of Figure 5-1, development of a typical CGE model begins with specification of baseline data that represents the economy in a single year. Normally, datasets used for this purpose are not consistent with the conditions necessary for the economy to be in equilibrium (e.g., output is not equal to consumption, inputs to production do not equal the value of output). Because of these factors, adjustments must be made to "calibrate" a baseline SAM that is consistent with these types of general equilibrium conditions. Once the underlying dataset has been constructed, functional forms are chosen that describe substitution possibilities available to firms and households. Then, because the calibration process only involves a single year's data, it is necessary to specify exogenous elasticity values, which control the ease of substitutions in the functional forms. Technically, the calibrated data determine the starting point for the production and utility functions, and the elasticities describe the curvature of the production isoquants and utility indifference curves around that starting point. When this process is complete and a replication check is run to ensure that the CGE model is fully specified and is initially in equilibrium, it is ready to be used for policy analyses.

The process of developing EMPAX-CGE has followed these steps, although additional calibration work was necessary, as discussed in Chapter 4, to allow the model to use a baseline dataset that accounts for expected economic growth and projected changes in energy markets between the year 2000 data and the starting year of the model. The figures and tables in Chapter 3 presented the functional forms and exogenous elasticity values in EMPAX-CGE. Based on these pieces of information, a baseline equilibrium is established by running a replication check of the model to ensure that all markets clear in the absence of new policies (supply equals demand, the value of inputs equal the value of output, etc.). At this point, a new "counterfactual" equilibrium can be computed for a policy change, which can be compared to the baseline solution to determine how the policy has altered the economy.

5.2 Environmental Policy Evaluation

When evaluating policies, the static version of EMPAX-CGE considers approximately 4,000 nonlinear equations, which must be solved simultaneously to determine baseline, and subsequently the counterfactual, equilibriums. Model development would not have been possible without the MPSGE software (Mathematical Programming Subsystem for General Equilibrium).[1] EMPAX-CGE is solved as a mixed complementarity problem (MCP)[2] running

[1]See Rutherford (1999) for MPSGE documentation.

[2]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.

within the GAMS[3] language (Generalized Algebraic Modeling System). The PATH solver from GAMS is used to solve the MCP equations generated by the MPSGE software.

EMPAX-CGE is capable of being applied to a wide range of environmental policies, and estimating how a change in a single part (or multiple parts) of the economy will influence economic behavior of firms and consumers across the United States. An essential component of its ability to analyze environmental policies is its inclusion of data on environmental protection expenditures made by firms. To reduce pollution, businesses typically must purchase emission control equipment and other production inputs from the rest of the economy. Accounting for these purchases is important because, in many cases, industries with high compliance costs will receive offsetting benefits as other types of companies buy more of their product, which partially reduces the burden of environmental regulations. For example, utilities have high environmental expenditures, but they also supply the electricity used by other firms to meet their own environmental standards. In addition, as expenditures on the goods and services necessary for compliance increase, firms producing these items may actually experience net benefits from regulatory action.

The importance of environmental protection activities in an economy has been investigated in previous studies (Schafer and Stahmer, 1989; Nestor and Pasurka, 1995). The goal of these papers was to improve estimates of environmental expenditures so that their contribution to gross national product could be more accurately measured. This was accomplished by developing I/O matrices showing the types of purchases made by firms to abate pollution. Schafer and Stahmer estimated an I/O matrix for Germany using 1980 data, and Nestor and Pasurka categorized environmental protection expenditures for the U.S. economy using a similar I/O framework based on 1977 and 1982 Census data.

EMPAX-CGE distributes estimated environmental protection costs across industries using data from Nestor and Pasurka (1995). This study, which is based on data from an EPA report (EPA, 1995b), provides a detailed I/O matrix of environmental protection expenditures by 41 industries in 1982. It shows how each industry's costs are allocated across purchases from other industries and also gives data on how much labor and capital were used. Table 5-1 displays these environmental protection activities for selected industries (chemicals, petroleum refining, and electric utility industries) as an example of the information available. The columns of the table represent industries required to comply with environmental regulation, while the rows represent the industries from which they purchased environmental protection goods and services.

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[3]See Brooke, Kendrick, Meeraus, and Raman (1998) for a description of GAMS (http://www.gams.com/).

Table 5-1. Distributions of Environmental Protection Expenditures for Selected Industries

Economic Sector/Factor	Chemicals	Petroleum Refining	Electric Utilities
Mining	0%	0%	47%[a]
Construction	7%	7%	4%
Textile mill products	0%	1%	0%
Chemicals and allied products	5%	3%	3%
Petroleum refining	1%	6%	2%
Stone clay and glass products	4%	5%	2%
Machinery except electrical	0%	1%	0%
Electric utilities	8%	15%	6%
Gas utilities	0%	1%	0%
Finance insurance and real estate	1%	2%	1%
Other services	17%	22%	7%
Water supply ("environmental")	2%	1%	0%
Sewerage systems	3%	0%	0%
Solid waste management services	10%	4%	4%
Labor	16%	18%	15%
Capital	24%	13%	11%
Total	100%	100%	100%

[a]Mining use by electric utilities represents low-sulfur coal purchases (data not used in EMPAX-CGE).

Source: Nestor, D.V., and C.A. Pasurka. 1995. "Environment-Economic Accounting and Indicators of the Economic Importance of Environmental Protection Activities." *Review of Income and Wealth* 41(3):265-287.

There are substantial differences in the distribution of costs between inputs across industries. For instance, the electric utility sector spends a very large proportion (47 percent) of their environmental protection expenditures on inputs purchased from the mining sector (most of which is low sulfur coal), while the chemicals and petroleum refining sectors do not spend any appreciable amount on these inputs. Expenditures on labor and capital generally account for a large share of environmental protection costs across all industries but still differ substantially across sectors in the total percentage devoted to these inputs and in the distribution between labor and capital.

EMPAX-CGE assumes, in the absence of any other information, that additional expenditures to meet new regulations (such as the operating costs for electricity generation or any compliance costs experienced by other industries) follow the patterns shown in the Nestor and Pasurka study.[4] Compliance costs are allocated across industries supplying environmental protection goods and services based on an assumption of constant shares. The only exception to this allocation approach is that electric utilities' purchases from the mining sector are ignored when determining the shares because these purchases (mainly of low-sulfur coal) were specific to policies in place in 1982. Also, because EMPAX-CGE can use results from the IPM model on fuel switching directly (as detailed in Appendix B), it is not necessary to include them in another, more indirect, fashion.

[4]Ideally, environmental protection I/O tables more recent than 1982 would be available. The levels in dollar values for baseline expenditures are probably quite different now than when the study data were collected. However, EMPAX-CGE uses expenditure shares, rather than the 1982 dollar values.

CHAPTER 6
DYNAMIC VERSION OF EMPAX-CGE

The dynamic version of EMPAX-CGE is designed to investigate policies that have variable effects over time. By modeling the future path of the economy, it is able to consider transitions that occur as the economy adapts to new policies. This version is based on the same data sources, production technologies, and household utility functions as the static version, but it includes additional features to allow it to model economic growth, investment decisions, and intertemporal behavior by households.

There are four sources of economic growth in the dynamic version of EMPAX-CGE: technological change from improvements in energy efficiency, growth in the available supply of labor from population growth and changes in labor productivity, increases in stocks of natural resources, and capital accumulation. Changes in energy use per unit of output are model through exogenous variables called autonomous energy efficiency improvements (AEEI), which are used to specify energy consumptions by fuel type and industry to replicate energy forecasts from EIA. Labor force growth, industrial output trends, changes in available natural resources, and resource prices are also based on the AEO forecasts. Decisions regarding capital formation also control many of the dynamic aspects of the model.

The representation of savings-investment decisions by households determines behavioral responses to policies. The dynamic version of EMPAX-CGE models these decisions using a forward-looking, full intertemporal optimization approach in which households have perfect foresight and maximize the present value of all future consumption.[1] This is in contrast to other dynamic CGE models that assume savings and investment are based only on the current time period's characteristics and that households are not forward looking.[2] By allowing agents to anticipate new policies, the EMPAX-CGE model shows how people will begin to prepare for policies that are announced today, but that will not begin until sometime in the future.

To investigate the dynamic implications of policies, the model must first establish a baseline path for the economy that incorporates economic growth and technology changes that are expected to occur in the absence of any new policies. The dynamic version of EMPAX-CGE begins from a balanced SAM that reflects economic conditions estimated by EIA for the year 2005. From this starting point, it solves in 5-year time intervals into the future and uses a variety of mechanisms (discussed in this chapter) to replicate the AEO energy and economic projections

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[1]The theoretical basis for these types of models includes Ramsey (1928), Cass (1965), and Koopmans (1965).
[2]Nonforward looking models are classified as recursive dynamic, e.g., MIT's EPPA model.

through the year 2025. Once this baseline is established, it is possible to run “counterfactual” policy experiments.

Section 6.1 discusses how the industry and regional data employed in the static version of EMPAX-CGE have been aggregated to allow the dynamic version to find solutions for multiple time periods while remaining within computational modeling limits. Section 6.2 describes the energy production and consumption forecasts used by the model and how they are replicated. Section 6.3 covers similar issues related to natural resources. Section 6.4 discusses the approach to modeling capital formation. Section 6.5 discusses household decisions and labor supply issues. Finally, Section 6.6 describes how a baseline equilibrium is established for the model and presents information on baseline growth paths for industries in the model.

6.1 Data Used by the Dynamic Version of EMPAX-CGE

The dynamic version of EMPAX-CGE relies on the same data sources as the static version of EMPAX-CGE and employs the same techniques discussed in Chapter 5 to generate an initial SAM for the economy based on AEO forecasts for the year 2005. From this starting point, it determines a growth path for the economy in the baseline by adjusting energy production and consumption, along with resource and labor changes, as discussed in following chapters.

Table 6-1 shows how industries in the dynamic version of EMPAX-CGE correspond to the wider array of sectors in the static model. The five main types of energy (coal, crude oil, electricity, natural gas, and petroleum) are maintained as separate industries because of their importance to environmental policies, although the petroleum refining sector only produces one type of oil instead of the original three categories (distillate fuel, motor gasoline, and other petroleum). Agriculture is also kept separate because it does not fit well in the other categories. Energy-intensive manufacturing industries (i.e., those businesses defined as high energy users according to EIA’s classification in “Assumptions to AEO 2003”) are also maintained as separate sectors. The remaining, less energy-intensive manufacturers are grouped together in a single category. Service industries are left as a distinct category because of the overall size of the service side of the economy, even though they use relatively little energy and are generally less affected by environmental policies. Transportation services are grouped together to reduce the size of the model, but they have not been merged with other types of services because they consume significant amounts of fuel and are vital for moving goods and people around the country.

A similar aggregation has been applied to regions in the model (see Figure 6-1). The goal of this process is to reduce the size of the dynamic model while keeping a regional categorization that maintains important differences in electricity generation and manufacturing industries across parts of the nation. In the Northeast, Midwest, and Southern parts of the United

Table 6-1. Industries in Dynamic Version and Correspondence to Static Version

Dynamic Version	Regional Static Version
Coal	Coal
Crude Oil	Crude Oil
Electricity *(fossil and nonfossil)*	Electricity *(fossil and nonfossil)*
Natural Gas	Natural Gas
Petroleum Refining[a]	Petroleum Refining[a]
Agriculture	Agriculture
Food	Food
Paper	Paper
Chemicals	Chemicals
Glass	Glass
Cement	Cement
Iron and Steel	Iron and Steel
Aluminum	Aluminum
Other Manufacturing	Construction
	Mining
	Beverages and Tobacco
	Textile Mills
	Textile Product Mills
	Apparel
	Leather
	Lumber and Wood
	Printing and Publishing
	Rubber and Plastic
	Other Nonmetallic Minerals (not including Glass or Cement)
	Other Primary Metals (not including Iron/Steel or Aluminum)
	Fabricated Metal
	Machinery
	Computer and Electrical Equipment
	Electronic Equipment
	Transportation Equipment (except Motor Vehicles)
	Motor Vehicles
	Furniture
	Miscellaneous
Services	Services
Transportation	Transport by Air
	Transport by Freight Truck
	Transport by Railroad
	Transport by Water
	Transport by Other

[a]The petroleum refining industry produces only one type of oil, rather than the three types produced in the static versions (distillate, motor gasoline, and other petroleum).

Figure 6-1. Regions in EMPAX-CGE (Dynamic Version)

*West also includes Alaska and Hawaii.

Note: Northeast = "NPCC+MAAC," Southeast = "SERC+FERC," Midwest = "ECAR+MAIN," Plains = "MAPP +SPP+ERCOT," and West = "WSCC." See http://www.nerc.com/ for further discussion of NERC regions.

States, two regions from the static model have been combined into a single more aggregated region. In the middle of the country, three regions have been merged. The West region remains the same as in the static version of EMPAX-CGE.

6.2 Energy Use

The baseline model solution for EMPAX-CGE needs to reflect the fact that energy consumption per unit of output tends to decrease over time through improvements in production technologies and energy conservation. Not incorporating these changes would cause the model to estimate unrealistically large costs for energy/environmental policies because the initial energy use would be too high. In addition, the baseline equilibrium must consider how industries shift from one energy source to another over time.

Figure 6-2 shows EIA estimates for fuel-use changes in two industries that rely heavily on energy: electricity generation and energy-intensive manufacturing (EIM). Utilities mainly use coal and gas to generate electricity, in addition to nonfossil sources. Consumption of both types of fuel is expected to increase in the future as demand for electricity grows, but there is a

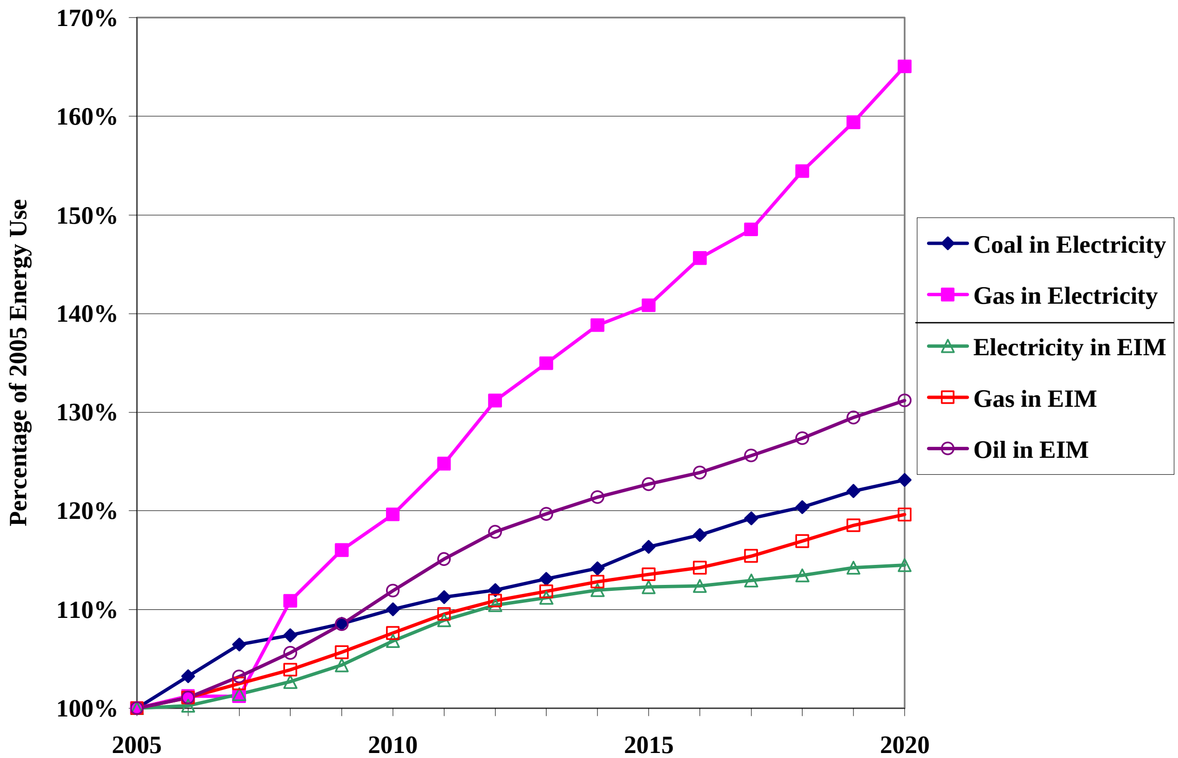

Figure 6-2. AEO's Changes in Energy Use for Selected Fuels/Industries

significant shift into gas-fired generation over the next 2 decades for a variety of reasons.[3] Similarly, EIM firms consume more energy in the future but are inclined to switch to oil, rather than to other fuels.

To capture these types of shifts in consumption, along with changes in energy efficiency, an autonomous energy efficiency improvement (AEEI) index for each fuel and each industry is developed that specifies the rate of decline in energy use per unit of output.[4] AEEIs 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.

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[3]In addition to variations in fuel use patterns expected from changes in prices and technologies, the AEO forecasts include effects that are expected to occur from legislation on the books at the time the forecasts are generated. This contributes to the shift away from coal and into gas as firms comply with existing environmental regulations.

[4]Edmonds and Reilly (1985) were the first to outline this approach. See Babiker et al. (2001) for a discussion of how this methodology was used in the EPPA model (EPPA assumes that AEEIs are the same across all industries in a country, while the AEEIs in EMPAX-CGE are industry specific).

Another important method of establishing baseline energy consumption patterns in the dynamic version of EMPAX-CGE is setting electricity generation by nuclear and renewable sources. The AEO forecasts provide estimates for future generation by these two sources, and EMPAX-CGE fixes nonfossil electricity output at these levels. This implies that the types of policies investigated by EMPAX-CGE will not be of a magnitude sufficient to overcome cost differentials between fossil and renewable generation, and that additional nuclear and renewable units will not be built as the result of these policies. If policies investigated by EMPAX-CGE in the future involve significant changes in electricity prices, this assumption will be altered to allow additional nonfossil generation.

6.3 Natural Resources

The final component of the dynamic version of EMPAX-CGE that controls the energy side of the economy is the modeling of how natural resources (coal, crude oil, and natural gas) evolve over time in price and quantity terms. AEO forecasts show prices and production quantities expected in the future, but they do not provide any information on the amount of the resources available in the ground for extraction or the costs associated with extracting additional materials. To overcome this limitation, EMPAX-CGE generates resource supply elasticities around the forecasted production paths.[5]

Resource supply elasticities reflect the fact that production costs rise as more is extracted and resources are depleted. By selecting the elasticities of substitution between the natural resources and other production inputs in these industries (elasticity σ_{gr} in Figure 3-6), the supply elasticity can be determined.[6] Price paths from AEO are also matched in EMPAX-CGE by adjusting the growth rates for the fixed factor inputs to resource production so that their prices in the baseline solution are calibrated to the desired forecasts.

6.4 Capital Stock and Adjustment Dynamics

Savings and investment decisions made by households determine aggregate capital stocks in the economy in the dynamic version of EMPAX-CGE. Characteristics of the formation of these stocks is described by the IMPLAN dataset, which provides details on the types of goods and services used to produce investment goods. The model uses this information to specify an aggregate investment sector that produces capital used by the economy. The data sources, however, do not contain a representation of initial capital stocks so it is necessary to calibrate

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[5]See Babiker and Rutherford (1997) and Rutherford and Paltsev (2000) for a discussion of how these techniques were used to incorporate the International Energy Agency energy data in the GTAP economic data.

[6]EMPAX-CGE uses an approach to natural resources that is similar to the EPPA model. Algebraic calculations can demonstrate that the resource supply elasticity (η^s) is equal to the substitution elasticity (σ_{gr}) adjusted by the share of inputs of natural resources used to produce output from the resource industry (S_{nr}):

$\eta^s = \sigma_{gr} * (1 - S_{nr}) / S_{nr}$.

them from observed earnings generated by the unobserved capital stock.[7] Typically, capital stock data, even if available, are not considered as reliable as capital earnings data so the calibration approach may be employed even if stocks are provided.[8]

Starting from the initial capital stock in the economy, the model has to specify how the stock evolves over time. These "adjustment dynamics" associated with formation of capital control the transition path the economy takes in response to new policies. In the dynamic version of EMPAX-CGE, these dynamics are controlled by using quadratic adjustment costs associated with installing new capital, which imply that real costs are experienced to build and install new capital equipment.

Following Uzawa (1969), EMPAX-CGE assumes that capital installation costs depend on the rate of gross investment in relation to the existing stock of capital. Costs of new capital decrease as the capital stock rises and vice versa. The installation cost function is given by

$$I_t = J_t\left(1+\phi\frac{J_t}{2K_t}\right)$$

where I_t is gross investment (in period t), J_t is net investment, K_t is the existing capital stock, and ϕ reflects the speed of adjustment.[9] The formulation implies that rapid changes in capital stocks are expensive and that the rate of adjustment will decline as adjustment costs increase.

Overall capital stocks are a function of this new net investment and depreciation (δ) of existing capital. The amount of capital available in the economy in the future is controlled by this equation:

$$K_{t+1} = K_t(1-\delta) + J_t$$

which shows how depreciation lowers available capital and net investment increases it. Net investment has to be sufficient to cover both economic growth (generating a need for additional capital in the future) and depreciation of existing capital. The capital stock generated in the model is perfectly malleable across industries within each of the five regions.

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[7]The rate of return to capital earnings includes the interest rate (r) plus the depreciation rate (δ). This is equal to the ratio of capital earnings (K_e) in the economy divided by the capital stock (K), allowing the stock to be calculated as $K_s = K / (r + \delta)$. Following the MIT EPPA model (Paltsev et al. [2003]), the real interest rate in EMPAX-CGE is set at 5 percent. Based on weighted average calculations of depreciation across capital assets and industries (see Table 7.10), the depreciation rate is assumed to be 7 percent.

[8]See Babiker et al. (2001) for a discussion of the EPPA model's calibration of capital stocks, which was done even though the underlying GTAP data included information on stocks.

[9]The capital adjustment cost parameter is set at 0.2 following Bovenberg and Goulder (2000), which was based on Summers (1981).

6.5 Households

As in the static version of EMPAX-CGE, the dynamic version of EMPAX-CGE is able to include multiple households in each region of the country, if desired. Although the dynamic version of EMPAX-CGE has computational limits that prevent all nine groups used in the static versions from being included, three or four income classes can be represented in each region. Prior to each run, the desired aggregation can be specified and normally includes (in cases where more than one household is needed):

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

These representative household(s) maximizes utility subject to its budget constraint. In the dynamic version of EMPAX-CGE, households have perfect foresight and maximize intertemporal utility over all time periods in the model. Within each period, intratemporal utility received by a household is formed from consumption of goods and leisure time according to the CES nesting structure shown in Figure 3-8. Over time, households consider the discounted present value of utility received from all periods' consumption of goods and leisure.

Because it is not computationally feasible to model an infinite number of time periods, EMPAX-CGE approximates an infinite horizon. This is done by separating the household's maximization decisions into two optimization problems, within model horizon (t = 0 to t = T) and post horizon (t = T + 1 to infinity).[10] The two problems are connected by the desired capital stock in T + 1. In each time period, *t*, households maximize intratemporal utility. Across time periods, the intratemporal utility, U_t (shown in Figure 3-6), is combined using a CES function to form intertemporal utility:

$$\max U = \left(\sum_{t=0}^{T} \left(\frac{1}{1+\gamma} \right)^{t} \left[U_t \right]^{\rho} \right)^{1/\rho}$$

where γ is the effective discount rate and the intertemporal elasticity of substitution, σ, is equal to $\sigma = 1/(1-\rho)$.[11] This intertemporal utility maximization is done subject to intertemporal budget and time constraints (abstracting from any government transfers or taxes):

[10]See Lau, Pahlke, and Rutherford (2000) for a discussion of this approach.

[11]The intertemporal elasticity of substitution is set equal to 0.5, following other works such as Goulder (2000) and Fullerton and Rogers (1993).

$$\sum_t p_t^c C_t = \sum_t w_t (L_t - LEIS) + pk_0 K_0 - pk_T K_T \quad LEIS + Labor = L_t$$

where p^c is the average price of consumption goods, C is total consumption, w is the wage rate, $LEIS$ is leisure time, L_t is the total labor endowment in time t, pk_0 is the price of capital in the initial time period, K_0 is the initial capital stock, pk_T is the price of capital in the terminal model period, and K_T is the supply of capital in the terminal period.

Labor earnings arise from an endowment of labor to households. This endowment grows over time as population and labor productivity grow. The model does not attempt to distinguish between these two sources of growth. Instead, it relies on exogenously specified growth rates in effective units of labor available to the economy. Using the assumption of Harrod-neutral technical change to represent increases in labor productivity allows EMPAX-CGE to include a labor augmentation parameter that covers both population growth and improvements in per-unit labor effectiveness. The growth parameter is based on AEO forecasts of overall economic growth.

At the beginning of the model horizon, in addition to labor endowments, households also own the existing capital stock, the value of which reflects expected future capital earnings generated from that stock. However, because the model solves an finite horizon problem it is necessary to remove the value of capital stocks remaining at the end of the model horizon.

6.6 Generation of a Baseline Model Solution

Before the dynamic version of EMPAX-CGE can be used to investigate a new policy, a baseline solution must be established for the model. In a dynamic model, this involves more steps than those discussed in Chapter 5 for the static model. Starting from the initial dataset representing the year 2005, the functional forms are chosen and exogenous elasticities are specified as before. Then a "steady-state" growth path is specified for the economy that is used as a replication check to ensure there are no errors in the model. Finally, the economy's growth and energy variables are matched to desired forecasts.

A steady-state growth path involves allowing all variables in the model to grow at a constant rate from the initial year out into the future. Labor and natural resource endowments grow at this constant rate (assumed to be 3 percent per year, based on the average GDP growth in the AEO forecasts). Output, inputs to production, and consumption also grow at this rate. If the model has been properly specified, the "steady-state" replication check will show that the economy is in an equilibrium along this constant-rate growth path. Once the model is able to replicate a steady-state growth path, desired forecasts can be applied to move the economy to a new baseline equilibrium that is based on expected future economic conditions.

The dynamic version of EMPAX-CGE incorporates a variety of AEO forecasts to allow it to reflect expected future economic conditions. These include

- energy consumption and output by industry and fuel type,
- nuclear/renewable electricity generation,
- natural resource prices, and
- labor endowments.

Growth paths for energy consumption are matched by the use of AEEIs that adjust the amount of fuel consumed by industries and households. These are calculated for each of the 17 sectors, 5 regions, and each household for each type of energy (coal, crude oil, electricity, natural gas, and petroleum). A series of iterative solves are conducted by the model to find AEEI coefficients that replicate the energy consumption and production forecasts. Each model solve estimates what the appropriate AEEI needs to be to match the forecasts. The model is then solved to determine the resulting energy uses, and these findings are compared to the desired result. The differences between the model solution values and the desired forecasts are used to adjust the AEEIs, and the model is resolved again until the baseline model solution is within a small percentage of the initial forecasts (generally within 0.1 percent – 0.5 percent of AEO's projections).

The amount of electricity generated by nuclear/renewable sources is easier to match to forecasts because of the assumption of fixed input coefficients in production. Households are endowed with a fixed factor input to nonfossil generation (e.g., some fraction of the capital used in generation) that is required to produce the electricity. By allowing this endowment to grow along the desired path, output from nonfossil sources is constrained to match forecasts.

Price paths for natural resources (coal, crude oil, and natural gas) are established using the process described in Section 6.3, which allows the model to replicate prices off the steady-state growth path. Labor endowments of the household(s) in each region in the dynamic version of EMPAX-CGE grow at exogenously specified rates based on AEO forecasts of economic growth, which are available at a Census Region level. These growth parameters cover both population growth and improvements in labor productivity and are one of the main sources of economic growth in the model.

The following tables present the results of this process for data in the baseline model solution of EMPAX-CGE, focusing on variables with the most significant impacts on results of energy and environmental policies (i.e., industrial growth and energy consumption forecasts). Table 6-2 shows regional industrial output revenues in dollars ($2000) and overall growth rates. Table 6-3 gives overall energy consumption in the United States for broad industrial and household groups in physical units (BTUs). Table 6-4 then presents details on energy consumption by fuel type for individual energy-intensive industries (food processing, paper, chemicals, glass, cement, iron and steel, and aluminum).

Table 6-2. Regional Industrial Output Revenues (in millions of $2000)

Region	Industry	2005	2010	2015	2020	2025	Growth Rate
Northeast	Coal	$3,077	$3,274	$3,344	$3,414	$3,500	0.6%
	Crude Oil	$4,247	$4,369	$4,158	$4,399	$4,395	0.2%
	Electricity	$35,542	$38,845	$40,945	$42,569	$44,677	1.2%
	Natural Gas	$1,282	$1,477	$1,621	$1,701	$1,843	1.8%
	Petroleum	$33,916	$37,111	$39,516	$40,749	$41,684	1.0%
	Agriculture	$27,467	$29,225	$30,245	$30,968	$31,514	0.7%
	Energy-Intensive Manufacturing	$289,800	$319,891	$346,720	$364,469	$380,554	1.4%
	Other Manufacturing	$808,941	$913,426	$1,029,742	$1,110,765	$1,193,982	2.0%
	Services	$2,850,601	$3,241,931	$3,698,110	$4,216,868	$4,789,777	2.6%
	Transportation	$131,112	$145,479	$161,111	$174,865	$188,872	1.8%
South	Coal	$2,346	$2,597	$2,913	$3,389	$3,932	2.6%
	Crude Oil	$9,529	$9,934	$9,598	$10,342	$10,514	0.5%
	Electricity	$58,478	$66,182	$73,612	$80,889	$88,231	2.1%
	Natural Gas	$30,482	$36,486	$41,877	$46,375	$52,648	2.8%
	Petroleum	$72,264	$82,845	$92,293	$100,845	$109,652	2.1%
	Agriculture	$52,821	$58,102	$62,582	$67,582	$72,341	1.6%
	Energy-Intensive Manufacturing	$219,499	$251,666	$287,736	$325,790	$363,046	2.5%
	Other Manufacturing	$842,265	$997,844	$1,181,094	$1,377,134	$1,582,974	3.2%
	Services	$2,386,490	$2,806,914	$3,318,032	$3,927,453	$4,615,169	3.4%
	Transportation	$142,921	$168,427	$198,986	$233,999	$270,880	3.2%
Midwest	Coal	$14,901	$16,074	$16,398	$16,691	$17,121	0.7%
	Crude Oil	$6,654	$6,867	$6,555	$6,979	$7,026	0.3%
	Electricity	$48,386	$53,238	$57,009	$60,874	$65,285	1.5%
	Natural Gas	$4,061	$3,940	$3,842	$3,957	$4,027	0.0%
	Petroleum	$51,364	$57,954	$63,353	$67,789	$72,458	1.7%
	Agriculture	$62,069	$66,468	$68,887	$71,514	$74,031	0.9%
	Energy-Intensive Manufacturing	$367,004	$402,754	$431,881	$458,386	$487,337	1.4%
	Other Manufacturing	$1,194,330	$1,362,453	$1,521,563	$1,688,572	$1,893,057	2.3%
	Services	$2,112,714	$2,403,792	$2,744,579	$3,140,943	$3,583,739	2.7%
	Transportation	$146,509	$163,553	$180,671	$199,338	$220,179	2.1%
Plains	Coal	$1,334	$1,446	$1,546	$1,637	$1,779	1.5%
	Crude Oil	$15,242	$15,892	$15,333	$16,443	$16,678	0.5%
	Electricity	$36,535	$41,084	$45,289	$48,907	$52,378	1.8%
	Natural Gas	$45,737	$51,626	$57,218	$61,980	$68,107	2.0%
	Petroleum	$116,637	$131,491	$144,148	$155,362	$167,058	1.8%
	Agriculture	$61,684	$68,191	$73,258	$77,872	$82,629	1.5%
	Energy-Intensive Manufacturing	$159,262	$183,228	$208,149	$230,159	$253,859	2.4%
	Other Manufacturing	$499,806	$619,512	$748,543	$852,730	$975,681	3.4%
	Services	$1,399,185	$1,622,838	$1,897,142	$2,219,716	$2,585,810	3.1%
	Transportation	$97,063	$114,773	$134,996	$154,697	$176,351	3.0%

(continued)

Table 6-2. Regional Industrial Output Revenues (in millions of $2000) (continued)

Region	Industry	2005	2010	2015	2020	2025	Growth Rate
West	Coal	$6,251	$7,115	$7,892	$8,639	$9,555	2.1%
	Crude Oil	$10,193	$10,698	$10,398	$11,241	$11,469	0.6%
	Electricity	$44,437	$50,730	$57,708	$65,007	$72,684	2.5%
	Natural Gas	$22,079	$24,980	$27,929	$31,256	$34,845	2.3%
	Petroleum	$78,216	$90,087	$100,526	$109,607	$119,407	2.1%
	Agriculture	$73,095	$82,353	$90,521	$98,657	$106,687	1.9%
	Energy-Intensive Manufacturing	$151,915	$178,707	$208,694	$237,984	$268,431	2.9%
	Other Manufacturing	$889,733	$1,144,805	$1,441,368	$1,713,304	$2,016,710	4.2%
	Services	$2,783,337	$3,262,012	$3,851,208	$4,556,626	$5,351,905	3.3%
	Transportation	$134,170	$162,283	$195,946	$232,120	$271,795	3.6%

Table 6-3. Energy Consumption by Sector in the United States (Quadrillion BTU)

Sector	Fuel	2005	2010	2015	2020	2025	Growth Rate
Residential (including motor gasoline)	Electricity	4.52	4.92	5.25	5.60	5.96	1.4%
	Natural Gas	5.49	5.71	5.91	6.19	6.47	0.8%
	Oil	18.30	20.79	22.95	24.77	26.62	1.9%
	Total	**28.31**	**31.42**	**34.11**	**36.56**	**39.05**	**1.6%**
Electricity	Coal	20.58	22.65	23.95	25.35	27.10	1.4%
	Natural Gas	5.79	6.92	8.13	9.51	10.68	3.1%
	Oil	1.81	1.80	1.70	1.70	1.72	–0.3%
	Total	**28.19**	**31.38**	**33.78**	**36.56**	**39.50**	**1.7%**
Petroleum Refining	Crude Oil	34.16	37.04	38.04	39.17	39.75	0.8%
	Electricity	0.13	0.16	0.18	0.18	0.19	1.8%
	Natural Gas	0.68	0.85	0.89	0.84	0.87	1.2%
	Oil	2.26	2.39	2.35	2.40	2.38	0.3%
	Total	**37.22**	**40.44**	**41.46**	**42.59**	**43.18**	**0.7%**
Agriculture	Coal	0.00	0.00	0.00	0.00	0.00	0.0%
	Electricity	0.19	0.21	0.22	0.23	0.24	1.3%
	Natural Gas	0.23	0.25	0.26	0.28	0.29	1.3%
	Oil	0.70	0.76	0.80	0.85	0.90	1.2%
	Total	**1.12**	**1.21**	**1.28**	**1.35**	**1.44**	**1.3%**
Energy-Intensive Manufacturing	Coal	1.66	1.69	1.69	1.66	1.65	0.0%
	Electricity	1.25	1.33	1.40	1.42	1.45	0.7%
	Natural Gas	4.32	4.65	4.91	5.17	5.51	1.2%
	Oil	4.10	4.58	5.03	5.38	5.76	1.7%
	Total	**11.33**	**12.25**	**13.02**	**13.63**	**14.36**	**1.2%**
Other Manufacturing	Coal	0.32	0.37	0.37	0.36	0.36	0.6%
	Electricity	1.65	1.98	2.25	2.49	2.79	2.7%
	Natural Gas	2.55	2.79	3.11	3.44	3.87	2.1%
	Oil	2.10	2.31	2.51	2.66	2.84	1.5%
	Total	**6.61**	**7.45**	**8.24**	**8.95**	**9.87**	**2.0%**
Services	Coal	0.07	0.07	0.07	0.08	0.08	0.9%
	Electricity	3.45	3.86	4.30	4.76	5.26	2.1%
	Natural Gas	2.74	2.87	3.03	3.24	3.45	1.2%
	Oil	0.46	0.48	0.48	0.49	0.49	0.3%
	Total	**6.72**	**7.28**	**7.89**	**8.57**	**9.27**	**1.6%**
Transportation	Coal	0.00	0.00	0.00	0.00	0.00	0.0%
	Electricity	0.08	0.09	0.09	0.10	0.11	1.8%
	Natural Gas	0.67	0.80	0.89	0.95	1.08	2.4%
	Oil	10.12	10.12	10.12	10.12	10.12	0.0%
	Total	**10.87**	**11.01**	**11.10**	**11.18**	**11.31**	**0.2%**
Total	Coal	22.80	24.96	26.28	27.66	29.40	1.3%
	Electricity	12.30	13.70	14.97	16.22	17.59	1.8%
	Natural Gas	24.40	26.86	29.29	31.90	34.67	1.8%
	Oil	40.12	45.02	49.11	52.73	56.61	1.7%
	Total	**99.61**	**110.53**	**119.66**	**128.51**	**138.27**	**1.7%**

Table 6-4. Energy Consumption by Components of Energy-Intensive Manufacturing (Quadrillion BTU)

Sector	Fuel	2005	2010	2015	2020	2025	Growth Rate
Food and Kindred	Coal	0.15	0.15	0.16	0.16	0.16	0.2%
	Electricity	0.22	0.23	0.24	0.25	0.26	0.9%
	Natural Gas	0.58	0.60	0.62	0.65	0.68	0.8%
	Oil	0.03	0.03	0.03	0.03	0.03	0.4%
	Total	**0.98**	**1.02**	**1.05**	**1.09**	**1.14**	**0.7%**
Paper and Allied	Coal	0.28	0.28	0.28	0.28	0.28	0.0%
	Electricity	0.21	0.21	0.22	0.22	0.22	0.2%
	Natural Gas	0.54	0.56	0.58	0.60	0.64	0.8%
	Oil	0.15	0.15	0.15	0.15	0.15	–0.1%
	Total	**1.19**	**1.21**	**1.23**	**1.25**	**1.29**	**0.4%**
Chemicals	Coal	0.18	0.18	0.18	0.18	0.18	0.1%
	Electricity	0.38	0.42	0.46	0.48	0.50	1.4%
	Natural Gas	2.49	2.75	2.98	3.19	3.44	1.6%
	Oil	3.81	4.30	4.74	5.09	5.47	1.8%
	Total	**6.87**	**7.65**	**8.36**	**8.94**	**9.60**	**1.7%**
Glass	Coal	0.00	0.00	0.00	0.00	0.00	0.0%
	Electricity	0.04	0.05	0.05	0.05	0.06	2.0%
	Natural Gas	0.14	0.15	0.16	0.17	0.18	1.4%
	Oil	0.01	0.01	0.01	0.01	0.01	0.6%
	Total	**0.19**	**0.21**	**0.22**	**0.24**	**0.26**	**1.5%**
Cement	Coal	0.22	0.24	0.25	0.25	0.25	0.8%
	Electricity	0.04	0.04	0.04	0.04	0.04	0.7%
	Natural Gas	0.02	0.02	0.02	0.02	0.02	–1.1%
	Oil	0.05	0.06	0.06	0.06	0.06	0.5%
	Total	**0.33**	**0.35**	**0.37**	**0.37**	**0.37**	**0.6%**
Iron and Steel	Coal	0.78	0.79	0.78	0.75	0.73	–0.4%
	Electricity	0.15	0.18	0.19	0.19	0.19	1.1%
	Natural Gas	0.39	0.41	0.41	0.40	0.39	0.0%
	Oil	0.03	0.03	0.04	0.03	0.03	–0.1%
	Total	**1.37**	**1.42**	**1.42**	**1.37**	**1.35**	**–0.1%**
Aluminum	Coal	0.03	0.03	0.03	0.03	0.03	0.0%
	Electricity	0.21	0.20	0.19	0.18	0.17	–1.0%
	Natural Gas	0.15	0.15	0.15	0.15	0.15	–0.1%
	Oil	0.01	0.01	0.00	0.00	0.00	–1.3%
	Total	**0.40**	**0.39**	**0.38**	**0.37**	**0.36**	**–0.6%**
Total	Coal	1.66	1.69	1.69	1.66	1.65	0.0%
	Electricity	1.25	1.33	1.40	1.42	1.45	0.7%
	Natural Gas	4.32	4.65	4.91	5.17	5.51	1.2%
	Oil	4.10	4.58	5.03	5.38	5.76	1.7%
	Total	**11.33**	**12.25**	**13.02**	**13.63**	**14.36**	**1.2%**

CHAPTER 7
TAXATION IN EMPAX-CGE

This chapter discusses the motivations for including taxes in EMPAX-CGE. It also describes the theoretical approaches used, data sources, and resulting estimates of tax rates. Although taxes have been incorporated in both the static and dynamic versions of EMPAX-CGE, the focus of this chapter, and that of any subsequent analyses of tax effects on estimated policy costs, is on the dynamic version of the model. Although taxes are included in the static version of EMPAX-CGE for consistency, the structure of a static model is unable to adequately represent all of the distortionary effects associated with taxes, especially those involving capital formation decisions occurring over time.

7.1 Overview

Tax distortions have been included in EMPAX-CGE because of the critical role that an existing tax structure can play in determining costs of a policy. If tax rates drive a wedge between the cost of producing a good and the price paid by the purchaser, producer and consumer behaviors will be distorted, giving rise to an excess burden beyond the revenue raised by the tax. Both theoretical and empirical literature have examined these “tax interactions” and found that they can substantially alter policy costs.[1] Consequently, it is important for EMPAX-CGE to consider how tax distortions may interact with policies when estimating their macroeconomic impacts.

The IMPLAN economic database used by EMPAX-CGE includes information on taxes such as indirect business taxes (all sales and excise taxes).[2] Payments related to the Federal Insurance Contribution Act, or FICA, taxes (i.e., Social Security plus Medicare) also appear as a direct claim on labor income by the government. However, IMPLAN follows National Income and Products Accounts (NIPA) conventions and reports factor payments at their gross-of-tax values. This implies that the tax payments and receipts associated with personal income taxes and corporate taxes are only reported as transfers between households and the government. Although these transfers can used to examine average tax rates, they do not show marginal tax rates.

However, the behavioral distortions caused by the existing tax structure are a function of marginal rates, not average rates. Marginal rates are what businesses consider (at the margin) when deciding whether to produce an additional unit of output. They are also what households

[1] See, for example, Goulder and Williams (2003), Goulder, Parry, and Burtraw (1997), Bovenberg and Goulder (1996), and Fullerton and Rogers (1993).

[2] These are modeled as *ad valorem* tax rates that drive a wedge between producer costs and purchaser prices.

examine when choosing whether to supply an additional unit of labor to firms, save more money for investment, and purchase another commodity from manufacturers. Given the critical nature of these decisions and their implications for policy costs, additional data on average marginal income tax rates (the tax rate paid, on average, on the last unit of income earned) are collected from a variety of federal and state government sources and included in EMPAX-CGE.

Along with marginal income taxes, a major effort of incorporating taxes in EMPAX-CGE involved developing an appropriate characterization of the cost of capital.[3] In dynamic models, taxes on capital can be relatively distortionary because they influence how people save and invest. This, in turn, affects how much capital is available for future production and can have significant effects on the results of policy simulations. Capital costs depend on a multitude of factors such as interest rates, depreciation, income tax rates (because households pay taxes on capital earnings), property taxes, and more. To specify these effects, EMPAX-CGE includes a user cost of capital structure based on the one applied by Fullerton and Rogers (1993) in their CGE model of tax policies.[4] The approach allows determination of a marginal effective tax rate for capital as a function of its important components, most notably the relationship between personal income tax rates and the cost of capital (as detailed in Section 7.3).

Distortions associated with taxes are a function of both marginal tax rates and labor supply decisions of households. As with other CGE models focused on interactions between tax and environmental policies (e.g., Bovenberg and Goulder [1996], Goulder and Williams [2003]), an important feature of EMPAX-CGE is its inclusion of a labor-leisure choice—how people decide between working and leisure time. Labor supply elasticities related to this choice determine, to a large extent, how distortionary taxes are in a CGE model. These elasticities and related variables are discussed in Section 7.4, along with implications for implied excess burdens associated with the final tax structure in EMPAX-CGE.

7.2 Labor Taxes

Effective labor taxes are a function of FICA taxes and personal income taxes (PIT). The IMPLAN data used in EMPAX-CGE track FICA taxes, covering both worker and employer contributions. However, IMPLAN does not contain information on PIT rates. Thus, average marginal tax rates at a state level are needed to represent existing labor market distortions. First, information is required on average incomes in each state to develop regional tax rates for the model. Data were collected on state-level wages and salary disbursements and employment statistics from the U.S. Bureau of Economic Analysis (BEA, 2004a). Using these data, average labor income for employees within each state is computed by dividing wage and salary earnings

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[3]See Jorgenson (1963) for development of theory related to capital costs and investment behavior.

[4]See Auerbach (1983) for a review of literature on the cost of capital, and CGE modeling work by Ballard et al. (1985) for additional information.

by employment figures. As shown in Table 7-1, the U.S. average value in 2000 was approximately $35,000 and state-level averages ranged from $24,000 (Montana) to $53,000 (District of Columbia).[5]

These average state-level earnings are combined with information from the TAXSIM model at the National Bureau of Economic Research (Feenberg and Coutts, 1993). TAXSIM is a microsimulation model of U.S. federal and state income tax systems. It can be used to estimate the average marginal tax rates needed for CGE analyses of taxes. As shown in Table 7-2, the TAXSIM model distinguishes rates by wage, interest, dividend, and capital-gains income. All four types of tax rates are used in Section 7.3 to calculate capital costs, and the wage tax rate is applied to labor earnings in EMPAX-CGE.

Following Ballard et al. (1985), EMPAX-CGE treats FICA as an *ad valorem* tax on labor and Social Security benefits as lump-sum transfers to households. Combining FICA taxes from the IMPLAN data with TAXSIM's average marginal wage tax rate gives a total labor tax rate of approximately 42 percent.[6] This is similar to the 40 percent figure often cited in literature and used in CGE models (e.g., Williams [1999], Goulder et al. [1999], Browning [1987]).

As with FICA taxes, EMPAX-CGE follows the approaches of Ballard et al. (1985) and Fullerton and Rogers (1993) related to modeling income taxes for different consumer groups (for EMPAX-CGE simulations that distinguish among household income classes). Income taxes are modeled as linear functions of income for each household, where households have different negative intercepts and a single positive marginal PIT rate. This captures differences in average tax rates and represents the progressive nature of the U.S. tax system, but it does not consider all of the complexities of graduated tax schedules (these are captured as much as possible by inclusion of state-specific PIT rates based on income differences across the country).

7.3 Capital Taxes

This section discusses the theoretical motivation and derivation of capital taxes used in EMPAX-CGE, describes the data sources, and reports the resulting tax rate estimates.

7.3.1 Theoretical Approach

A characterization in a CGE model of marginal effective tax rates (METR) on capital needs to account for features such as

- how corporate tax rates affect the cost of capital,

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[5] All data and tax rates used in calculations in this chapter are for the year 2000, which is the year of the IMPLAN database, because distortions in the economic data will reflect these year 2000 tax rates.

[6] Average FICA payments in the IMPLAN data represent an approximately 13 percent tax rate, which takes into account phasing out of employee contributions above certain income levels.

Table 7-1. Wage and Salary Data by State: 2000

State	Wages and Salary Disbursements ($$10^3$)	Share of Total	Average Per Employee
Alabama	$57,665,183	1.2%	$28,302
Alaska	$10,737,354	0.2%	$34,509
Arizona	$76,132,203	1.6%	$32,232
Arkansas	$31,502,457	0.7%	$25,683
California	$638,516,462	13.2%	$40,386
Colorado	$86,047,975	1.8%	$36,397
Connecticut	$79,104,638	1.6%	$44,556
Delaware	$15,813,877	0.3%	$35,616
District of Columbia	$37,528,953	0.8%	$52,642
Florida	$228,618,219	4.7%	$30,217
Georgia	$140,787,389	2.9%	$33,542
Hawaii	$19,269,829	0.4%	$30,504
Idaho	$16,562,466	0.3%	$27,091
Illinois	$236,443,363	4.9%	$37,390
Indiana	$94,920,538	2.0%	$30,288
Iowa	$42,278,622	0.9%	$27,185
Kansas	$41,300,785	0.9%	$28,675
Kentucky	$54,349,107	1.1%	$28,076
Louisiana	$55,632,549	1.2%	$27,156
Maine	$17,216,713	0.4%	$27,227
Maryland	$93,927,303	1.9%	$35,878
Massachusetts	$151,330,003	3.1%	$43,261
Michigan	$175,593,351	3.6%	$36,251
Minnesota	$96,584,566	2.0%	$34,582
Mississippi	$30,792,285	0.6%	$24,563
Missouri	$88,902,109	1.8%	$30,701
Montana	$9,983,381	0.2%	$24,020
Nebraska	$26,591,534	0.6%	$27,650
Nevada	$35,196,823	0.7%	$32,682
New Hampshire	$21,913,987	0.5%	$33,930
New Jersey	$176,256,233	3.6%	$42,866
New Mexico	$21,783,898	0.5%	$27,518
New York	$402,269,427	8.3%	$44,755
North Carolina	$127,573,645	2.6%	$30,469
North Dakota	$8,437,564	0.2%	$24,302
Ohio	$186,482,963	3.9%	$31,825
Oklahoma	$41,911,087	0.9%	$26,438
Oregon	$54,783,067	1.1%	$32,222
Pennsylvania	$197,968,339	4.1%	$33,209
Rhode Island	$16,079,486	0.3%	$31,905
South Carolina	$54,783,091	1.1%	$27,579
South Dakota	$9,713,784	0.2%	$24,238
Tennessee	$85,342,743	1.8%	$29,859
Texas	$342,028,104	7.1%	$34,210
Utah	$32,655,094	0.7%	$28,709
Vermont	$8,964,725	0.2%	$28,154
Virginia	$131,878,351	2.7%	$34,656
Washington	$110,051,355	2.3%	$37,420
West Virginia	$19,393,926	0.4%	$26,249
Wisconsin	$87,890,180	1.8%	$30,006
Wyoming	$6,762,914	0.1%	$26,549
United States	**$4,834,254,000**	**100.0%**	**$34,647**

Source: U.S. Bureau of Economic Analysis (BEA). 2004a. "Detailed Income and Employment Tables by SIC Industry 1958–2001." <http://www.bea.gov/bea/regional/spi/default.cfm>. As obtained January 2004.

Table 7-2. Average Marginal Effective Income Tax Rates by Type and State: 2000

Name	Wages	Interest	Dividends	Long-Term Capital Gains
Alabama	27.0%	26.2%	29.7%	22.7%
Alaska	26.0%	26.8%	24.9%	17.6%
Arizona	27.8%	28.0%	27.5%	22.4%
Arkansas	29.4%	25.2%	30.6%	17.8%
California	32.3%	31.3%	33.1%	26.0%
Colorado	29.7%	28.2%	30.8%	22.2%
Connecticut	32.3%	29.3%	33.3%	23.4%
Delaware	30.7%	27.1%	28.7%	26.5%
District of Columbia	36.3%	36.8%	36.8%	31.9%
Florida	24.0%	23.9%	25.0%	18.8%
Georgia	30.4%	29.8%	32.0%	25.2%
Hawaii	32.9%	31.7%	31.8%	24.5%
Idaho	30.3%	25.5%	29.1%	18.3%
Illinois	28.7%	27.9%	29.7%	22.5%
Indiana	28.3%	25.9%	27.9%	22.5%
Iowa	28.6%	27.5%	29.1%	21.2%
Kansas	30.9%	33.8%	32.2%	26.2%
Kentucky	29.6%	28.4%	30.7%	23.6%
Louisiana	27.2%	28.5%	35.1%	23.0%
Maine	28.7%	30.8%	35.9%	26.7%
Maryland	31.0%	29.4%	30.9%	25.4%
Massachusetts	32.0%	29.6%	32.1%	24.7%
Michigan	30.2%	27.6%	30.3%	22.8%
Minnesota	32.9%	30.2%	34.2%	26.0%
Mississippi	25.3%	26.7%	29.0%	21.8%
Missouri	29.4%	27.9%	30.9%	24.1%
Montana	26.9%	30.4%	23.6%	14.6%
Nebraska	28.2%	29.6%	33.0%	25.6%
Nevada	24.5%	25.6%	27.3%	19.6%
New Hampshire	24.6%	30.7%	28.1%	16.5%
New Jersey	31.4%	28.8%	31.7%	22.9%
New Mexico	29.1%	27.9%	34.2%	23.9%
New York	33.1%	30.7%	32.9%	25.5%
North Carolina	30.6%	29.3%	32.4%	26.4%
North Dakota	27.1%	27.1%	30.2%	18.6%
Ohio	29.9%	27.6%	30.6%	24.3%
Oklahoma	29.8%	28.0%	31.1%	18.6%
Oregon	33.1%	34.2%	30.3%	26.4%
Pennsylvania	27.8%	26.1%	28.5%	21.3%
Rhode Island	32.0%	29.7%	36.2%	24.6%
South Carolina	30.0%	29.4%	34.0%	23.4%
South Dakota	19.4%	21.1%	24.7%	16.5%
Tennessee	23.9%	28.6%	33.7%	18.1%
Texas	24.4%	24.2%	26.9%	18.7%
Utah	29.2%	29.8%	32.7%	25.7%
Vermont	30.4%	22.4%	22.9%	22.8%
Virginia	31.1%	30.8%	31.9%	24.5%
Washington	24.4%	22.1%	24.8%	18.3%
West Virginia	27.4%	34.0%	33.2%	27.0%
Wisconsin	32.0%	30.9%	32.0%	20.5%
Wyoming	22.8%	15.0%	29.1%	18.3%
Weighted Average	**29.5%**	**28.5%**	**30.7%**	**23.2%**

Source: NBER TAXSIM Model at <http://www.nber.org/~taxsim/> (Feenberg and Coutts, 1993).

- how PIT paid on capital earnings influence capital costs,
- how economic depreciation of capital assets (which depends on asset type) alters costs,
- how corporate structures in different industries shape treatment of capital taxes, and
- how capital taxes vary across industries as a result of these interactions.

EMPAX-CGE determines effective capital tax rates by applying the user cost of capital methodology. The theoretical basis for this approach has a long history (see Auerbach [1983] for a review of the method) and has been used in applied general equilibrium models by other researchers such as Fullerton and Rogers (*Who Bears the Lifetime Tax Burden?* [1993]), subsequently referred to as FR. The FR documentation of how capital taxes were incorporated into their CGE model is relatively unique in its level of detail, both in terms of calculations and the associated data sources and parameter estimates. For these reasons, EMPAX-CGE uses a similar approach, although data used in the calculations have been updated where feasible.

Effective capital costs reflect interactions among a number of variables such as statutory corporate tax rates, PIT on capital earnings, effects of incorporation levels on tax payments, property taxes, and differential tax and depreciation treatments for various types of financial assets. One reason for adopting the FR approach is that it makes these interactions explicit (including relationships with the most implications for model results, i.e., between PIT and capital costs). Tables 7-3 and 7-4 define parameters used in the computations, followed by a discussion of the relevant equations.

For corporations, the cost of financing is a function of interest payments on debt, costs of retained earnings, and costs of new shares.[7] As a weighted average across financial instruments, the overall corporate discount rate can thus be expressed as

$$r_c = c_d r_d + c_{re} r_{re} + c_{ns} r_{ns} \tag{7.1}$$

and the noncorporate discount rate can be expressed as

$$r_{nc} = n_d r_d + n_e r_e. \tag{7.2}$$

Arbitrage conditions among these rates of return will ensure that they are all equal on a net-of-tax basis, which implies that capital costs can be calculated from the net real return to holding debt [$r = i(1 - \tau_d) - \pi$] and leads to the following calculations. Because debt financing charges are deductible at the statutory corporate tax rate, firms pay the equivalent of the nominal

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[7]Following FR assumptions, EMPAX-CGE assumes that industries have fixed financial structures.

Table 7-3. Parameter Definitions (following FR notation)

Parameter	Description
ρ_c^k	Corporate sector gross-of-tax capital costs of type k
ρ_{nc}^k	Noncorporate sector gross-of-tax capital costs of type k
i	Nominal interest rate
r_c	Corporate sector discount rate (weighted average)
r_{nc}	Noncorporate sector discount rate (weighted average)
r_d	Discount rate on debt financing
r_{re}	Discount rate on retained earnings
r_{ns}	Discount rate on new shares
r_e	Discount rate on equity
w_k	Property tax rate on capital of type k
δ_k	Economic depreciation rate of capital of type k
z_c^k	Present value of depreciation allowance for corporate capital of type k
z_{nc}^k	Present value of depreciation allowance for noncorp capital of type k

Table 7-4. Exogenous Variable Values (following FR notation)

Variable	Description	Value	Source
r	Real interest rate	0.05	MIT EPPA model
π	Inflation rate	0.03	AEO 2003 (Table 20)
u_f	Statutory federal corporate tax rate	0.35	IRS Publication 542
u_s	Statutory state corporate tax rates	~0.06	See Table 7-5
u	Statutory corporate tax rate	~0.39	See Table 7-8
τ_{PIT}	Personal income tax rate	~0.29	See Table 7-2
τ_d	Income tax rate on interest income (debt financing)	~0.28	See Table 7-2
τ_{re}	Income tax rate on accrued capital gains (retained earnings)	~0.05	FR and Table 7-2
τ_{ns}	Income tax rate on dividend income (new shares)	~0.28	See Table 7-2
τ_{nc}	Income tax rate on noncorporate income (or PIT)	~0.29	See Table 7-2
c_d	Proportion of corporate investment financed by debt	0.34	FR (Table 3-17)
c_{re}	Proportion of corporate investment financed by retained earnings	0.33	FR (Table 3-17)
c_{ns}	Proportion of corporate investment financed by new shares	0.33	FR (Table 3-17)
n_d	Proportion of noncorporate investment financed by debt	0.34	FR (Table 3-17)
n_e	Proportion of noncorporate investment financed by retained earnings	0.67	FR (Table 3-17)

interest rate excluding the statutory rate [$r_d = i(1 - u)$]. For retained earnings, the nominal net return is the corporation's discount rate, which is a function of taxes paid on debt and the tax rate applied to retained earnings [$r_{re} = i(1 - \tau_d)/(1 - \tau_{re})$]. Similarly, the nominal net return for new shares is a function of taxes paid on debt and on dividend earnings [$r_{ns} = i(1 - \tau_d)/(1 - \tau_{ns})$]. Eq. (7.3) presents these three components of the corporate discount rate, weighted by the shares of each in overall corporate financing:

$$r_c = c_d \left[i(1-u) \right] + c_{re} \left[i(1-\tau_d)/(1-\tau_{re}) \right] + c_{ns} \left[i(1-\tau_d)/(1-\tau_{ns}) \right]. \qquad (7.3)$$

For firms with a noncorporate structure, interest payments are deductible at the personal income rate applied to equity earnings. Equity returns must equal the return to holding debt because of arbitrage conditions. Eq. (7.4) give these two components of the noncorporate discount rate, which are weighted by the shares of each in overall noncorporate financing:

$$r_{nc} = n_d \left[i(1-\tau_{nc}) \right] + n_e \left[i(1-\tau_d) \right]. \qquad (7.4)$$

Using the arbitrage condition to determine the real return to capital, r, and simplifying the FR equations by assuming that the PIT is applied to equity returns of noncorporate firms, implies that Eqs. (7.3) and (7.4) can be expressed as[8]

$$r_c = c_d \left[((r+\pi)/(1-\tau_{PIT}))(1-u) \right] + c_{re} \left[(r+\pi)/(1-\tau_{re}) \right] + c_{ns} \left[(r+\pi)/(1-\tau_{ns}) \right] \qquad (7.5)$$

$$r_{nc} = n_d \left[(r+\pi)(1-\tau_{PIT})/(1-\tau_d) \right] + \mathrm{n}_e \left[(r+\pi) \right]. \qquad (7.6)$$

After these real returns to capital have been determined, they can be incorporated into an expression of a firm's profit-maximization decision to determine gross-of-tax costs of capital, following the methodology of Hall and Jorgenson (1967) as described in Fullerton and Lyon (1988) and Fullerton and Rogers (1993). Eqs. (7.7) and (7.8), adapted from FR,[9] illustrate these calculations for each type of capital asset, k (equipment, structures, inventories, land, and intangibles such as knowledge). The capital costs are expressed as functions of real returns, inflation, depreciation, PIT, the present value of depreciation allowances (z, which is equal to allowances divided by allowances plus real net returns), and property taxes:

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[8] τ_{re} is assumed to be equal to one quarter of the long-term capital gains rate, following Fullerton and Rogers (1993). This reflects the fact that taxes on capital gains can be postponed by not realizing the gains until a future date, thereby lowering the effective tax rate.

[9] The original FR equations included discounts for investment tax credits that have since been phased out.

$$\rho_c^k = \frac{r_c - \pi + \delta_k}{1-u}\left(1 - uz_c^k\right) + \omega_k - \delta_k \qquad (7.7)$$

$$\rho_{nc}^k = \frac{r_{nc} - \pi + \delta_k}{1-\tau_{PIT}}\left(1 - \tau_{PIT}\ z_{nc}^k\right) + \omega_k - \delta_k \qquad (7.8)$$

METRs for capital can then be calculated for each asset class and corporate structure as the difference between the gross-of-tax capital cost (ρ) minus the net-of-tax cost (r) divided by the gross-of-tax cost. These METR summarize the effects of all taxes applied to capital and characterize how changes in components of METR will affect the cost of capital. Using the data discussed below, EMPAX-CGE develops a weighted average of METR for each industry across all asset types and firm structures, based on the industry's share of corporate and noncorporate assets and associated types of capital.

7.3.2 Data and Estimated Capital Tax Rates

One of the motivations for choosing the approach to estimating capital taxes used by Fullerton and Rogers (1993) is that they provide detailed information on their parameter estimates and data sources. Where feasible, the parameters, and sources used to develop capital stock estimates underlying user cost of capital calculations, have been updated to the year 2000, consistent with the base year of the IMPLAN database.

Table 7-5 shows state-specific statutory corporate tax rates. These are combined with the top bracket, federal statutory rate of 35 percent to determine regional corporate tax rates (see Table 7-8). Although there may be differences between the location of capital earnings shown in the IMPLAN state-level data and the location where corporate taxes are assessed, these differences are assumed away at the regional level used in EMPAX-CGE.

Along with updating statutory corporate tax rates, the data sources used by EMPAX-CGE to calculate capital assets by industry are based on year 2000 information where possible. As illustrated in Section 7.3, the user cost-of-capital equations require data on five types of assets (equipment, structures, inventory, land, and intangibles) owned by two different types of firms (corporate and noncorporate).

Data on equipment and structures owned by industries are available from the U.S. Bureau of Economic Analysis (BEA, 2004b). However, these data do not distinguish asset values by corporate and noncorporate organizations. For this, BEA data that separate out legal organization forms by broad industry category are employed (see Table 7-6).

Table 7-5. Corporate Marginal Tax Rates by State: 2000[a]

Name	State Corporate
Alabama	5.0%
Alaska	9.4%
Arizona	8.0%
Arkansas	6.5%
California	8.8%
Colorado	4.6%
Connecticut	7.5%
Delaware	8.7%
District of Columbia	10.0%
Florida	5.5%
Georgia	6.0%
Hawaii	6.4%
Idaho	8.0%
Illinois	4.8%
Indiana	3.4%
Iowa	12.0%
Kansas	4.0%
Kentucky	8.3%
Louisiana	8.0%
Maine	8.9%
Maryland	7.0%
Massachusetts	9.5%
Michigan	2.1%
Minnesota	9.8%
Mississippi	5.0%
Missouri	6.3%
Montana	6.8%
Nebraska	7.8%
Nevada	0.0%
New Hampshire	8.0%
New Jersey	9.0%
New Mexico	7.6%
New York	8.0%
North Carolina	6.9%
North Dakota	10.5%
Ohio	8.5%
Oklahoma	6.0%
Oregon	6.6%
Pennsylvania	10.0%
Rhode Island	9.0%
South Carolina	5.0%
South Dakota	0.0%
Tennessee	6.0%
Texas	0.0%
Utah	5.0%
Vermont	9.8%
Virginia	6.0%
Washington	0.0%
West Virginia	9.0%
Wisconsin	7.9%
Wyoming	0.0%

[a] The majority of states have only one tax bracket for corporations; however, some states have multiple brackets. In these cases, consistent with Fullerton (1987), EMPAX-CGE uses the top bracket in its calculations.

Source: The Tax Foundation. *State Corporate Income Tax Rates*. As of December 31, 2000.

Table 7-6. Equipment and Structures Assets: Corporate and Noncorporate Sectors

Asset Type	Corporate	Noncorporate
Farms		
Equipment and software	11%	89%
Structures	7%	93%
Manufacturing		
Equipment and software	98%	2%
Structures	98%	2%
Nonfarm nonmanufacturing		
Equipment and software	86%	14%
Structures	69%	31%

Source: U.S. Bureau of Economic Analysis (BEA). 2004c. "Current-Cost Net Stock of Nonresidential Fixed Assets by Industry Group and Legal Form of Organization, Table 4-1." <http://www.bea.doc.gov/bea/dn/faweb/AllFATables.asp>. As obtained January 2004.

Data on inventories and land come from two government sources. The U.S. Census Bureau publishes asset data for inventory and land for selected mining and manufacturing industries in the *Quarterly Manufacturing Reports* (U.S. Bureau of the Census, 2001). Similarly, the U.S. Department of Agricultural estimates land assets in the agricultural sector in the *Agricultural Economics and Land Ownership Survey* (USDA, 2000). For the majority of the mining and manufacturing data, asset values are distinguished by corporate and noncorporate sectors using the Federal Reserve Board's *Flow of Funds Accounts* (see Table 7-7). In cases where updated information could not be identified, data from Fullerton and Rogers (1993) were used to estimate asset distributions.

The final category of assets, intangibles, is established using the methodology described in Fullerton and Lyon (1988). Intangible capital (i.e., knowledge or information) requires investment by firms but is treated differently than other types of assets (in part because there is no tangible asset to measure). The kinds of investments used to develop intangible capital include advertising expenditures, research and development (R&D), and expenses related to training and customer relations. Unlike other assets, these investments are usually deducted from business income immediately, rather than being depreciated over time. This preferential tax treatment has implications for capital tax rates that are accounted for by the user cost of capital approach.

Table 7-7. Inventory and Land Assets: Corporate and Noncorporate Sectors

Asset Type	Corporate	Noncorporate
Land	70%	30%
Inventory	75%	25%

Source: Federal Reserve Board. 2004. *Flow of Funds Accounts of the United States*, Coded Tables for Z.1 Release. Tables B.102 and B.103. <http://www.federalreserve.gov/releases/Z1/20040115/Coded/coded.pdf>. As obtained January 2004.

Following Fullerton and Lyon (1988), intangible capital stocks are assumed to comprise the depreciated present values of advertising and R&D expenditures. The U.S. Internal Revenue Service publishes flows of advertising deductions by industry (U.S. IRS, 1995–2001). Implied capital stocks associated with these flows are computed using data for the period 1994–2000, based on an annual depreciation rate of 33 percent. Asset values connected to R&D expenditures are taken from the National Science Foundation's (NSF) *Industrial Research and Development Information System*. Data by industry from 1980 to 2000 (NSF, 2001a and 2001b) are employed to estimate capital stock values using an annual depreciation rate of 15 percent. In the absence of other data, Fullerton and Lyon (1988) data are used to distribute these stocks between corporate and noncorporate sectors.

Following this process, findings on the five types of capital assets by industry are combined with the data developed on personal income and statutory corporate tax rates (see Table 7-8). Information from Fullerton and Rogers (1993) on depreciation and property taxes is also used (see Table 7-9), along with general EMPAX-CGE assumptions about real interest rates (set at 5 percent, following the MIT EPPA model). This collection of data is sufficient to allow calculation of the marginal effective tax rates on capital, based on Eqs. (7.1) to (7.8).

Table 7-8. Regional Tax Rates

Region	PIT	State Corporate[10]	Combined State and Federal Corporate[a]
Northeast	31.4%	8.6%	40.6%
South	27.8%	6.0%	38.9%
Midwest	29.5%	6.2%	39.0%
Plains	26.8%	2.5%	36.6%
West	30.5%	6.9%	39.5%

[a] The total statutory corporate tax rate, based on combined state plus federal corporate tax rates, is calculated according to the method used in Fullerton [1987] as federal (35 percent) + state * (1 – federal).

[10] Capital earnings in each state from the IMPLAN data are used to weight the corporate tax rates across states within regions.

Table 7-9. Cost Data by Type of Capital

Capital Type	Economic Depreciation	Depreciation Allowance	Property Tax Rate
Equipment	0.1300	0.3400	0.00574
Structures	0.0300	0.1350	0.00865
Inventories	0.0000	0.0000	0.00574
Land	0.0000	0.0000	0.00865
Intangibles	0.2100	1.0000	0.00000

Source: Fullerton, D., and D. Rogers. 1993. "Who Bears the Lifetime Tax Burden?" Washington, DC: The Brookings Institute, except property taxes from authors' calculations (see text).

Calculations of average effective property tax rates are based on King and Fullerton (1984), which are updated using NIPA data (U.S. BEA, 2004d) on state and local property tax receipts from year 2000. These data are available as a total figure covering personal and business property taxes (equal to $254 billion). Information from King and Fullerton (1984) on the relative shares of business property taxes in total property taxes, separated into land and structures versus equipment and inventories, is used to apportion this total. Multiplying the shares by total property taxes and then dividing the resulting figure by total capital assets of each type (see Table 7-10) gives the property tax rates shown in Table 7-9.

Table 7-10 presents the results of the estimates of capital assets by industry and associated marginal tax rates for the 40 sectors in the regional static version of EMPAX-CGE. For the dynamic version, weighted average rates across relevant industries are used. Unlike the FR model, EMPAX-CGE does not explicitly track asset and firm types once effective tax rates by industry have been estimated. Consequently, the weighted average METR enters EMPAX as a tax on capital earnings by industry. These estimated METR range from around 25 percent in industries such as computers that depend heavily on R&D assets that can be deducted from business profits immediately to more than 40 percent in sectors such as iron and steel where assets mainly comprise equipment and structures that receive less favorable tax treatment.[11]

Table 7-11 presents the capital asset and METR findings of Fullerton and Rogers (1993) as a weighted average over corporate and noncorporate structures. A comparison of these data to EMPAX-CGE estimates indicates that effective capital tax rates remain around 40 percent for most industries, although there have been changes in tax laws (i.e., reductions in statutory corporate tax rates—FR uses 49.5 percent—and investment tax credits considered in the FR

[11]As noted in Fullerton (1987), METR tend to show less variation across industries than average tax rates. Thus, use of METR will imply lower overall distortions from capital taxes in a CGE model than average rates.

calculations have been eliminated).[12] The 40 percent figure is similar to what is typically assumed in CGE modeling of tax distortions (e.g., Goulder et al. [1999]).

7.4 Labor Supply Decisions and Tax Distortions

The motivation for including taxes in EMPAX-CGE is to adequately represent how interactions between the existing tax structure and new policies will alter estimated macroeconomic results. Aside from the specific marginal tax rates included in a CGE model, the parameter with the greatest impact on distortionary effects associated with taxes is the labor-supply elasticity. This elasticity controls how willing households are to substitute between leisure time and supplying labor to businesses. If households are very willing to switch between leisure and work in response to changes in wages, existing labor taxes will have significantly distorted economic behavior from what would have occurred in the absence of the taxes, implying a large excess burden for labor taxes, and the reverse if households are not willing to substitute leisure time for work (and hence consumption goods).

Existing taxes on labor income have two effects on labor supply: a *substitution effect*—a reduction in the amount of labor available for production because they lower income received by households providing the labor and an *income effect*—an increase in work effort due to the fact that taxes have lowered overall income levels. Which of these two effects dominates is an empirical question. Russek (1996) reviews relevant literature, which cites estimates for total labor supply elasticities (covering both women and men) ranging between –0.1 and 2.3. Fuchs, Krueger, and Poterba (1998) also review estimated elasticities with similar findings.

The values for labor-supply elasticities most commonly used in CGE models are in the mid-point of the range presented by Russek—typically around 0.4 for compensated elasticities and 0.15 for uncompensated elasticities (e.g., Parry and Bento [2000], Williams [1999], Goulder, Parry, and Burtraw [1997], Bovenberg and Goulder [1996]). In the CGE model, the elasticity of substitution between consumption goods and leisure (σ_{cl}) and the total time endowment (L_t) can be selected to yield the desired compensated (η_c) and uncompensated (η_{uc}) labor-supply elasticities according to the equations: (1) $\theta = \eta_c - \eta_{uc}$, (2) $LEIS_t = C_t * (\theta/(1-\theta)$, (3) $L_t = LEIS_t + Labor$, (4) $\sigma_{cl} = \eta_c / (1-\theta) * (Labor / LEIS_t)$; where $LEIS_t$ is leisure time, C_t is total consumption of goods, and θ is the income elasticity of labor supply.

Selection of labor-supply elasticities for a CGE model must also take into consideration its implications for measurements of how distorting existing taxes are in the model. These distortions are typically measured in two ways: marginal cost of public funds (MCPF) and

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[12] FR used a 4 percent real interest rate and a 4 percent inflation rate. EMPAX-CGE uses a 5 percent real interest rate and a 3 percent inflation rate so these variables have equivalent effects.

Table 7-10. U.S. Industry Capital Stocks and Weighted Average Marginal Effective Capital Tax Rates

General Classification	Industry in EMPAX-CGE	Percent of Total Capital: Equipment	Structures	Inventories	Land	Intangibles	Total Capital in 2000 ($million)	Marginal Effective Tax Rate
Energy	Coal	32.4%	52.2%	1.2%	13.1%	1.0%	$54,431	41.1%
	Crude Oil	12.7%	80.1%	0.6%	6.2%	0.5%	$508,043	40.4%
	Electricity	20.8%	50.2%	2.2%	26.6%	0.3%	$1,096,476	40.0%
	Natural Gas	11.3%	58.2%	2.1%	28.0%	0.4%	$363,872	39.8%
	Petroleum Refining	26.8%	35.9%	10.4%	16.6%	10.3%	$156,400	42.5%
Non-Manufacturing	Agriculture	19.0%	25.0%	6.0%	49.9%	0.1%	$991,706	35.8%
	Construction	19.0%	8.9%	47.7%	22.6%	1.8%	$515,704	45.2%
	Mining	31.1%	55.3%	1.1%	11.5%	1.0%	$73,585	40.9%
	Services	29.6%	51.9%	3.3%	8.6%	6.5%	$7,253,948	38.7%
	Transport by Air	65.3%	11.6%	2.6%	19.6%	0.9%	$222,728	40.6%
	Transport by Freight Truck	44.9%	29.1%	2.4%	22.7%	0.8%	$172,022	40.2%
	Transport by Railroad	10.6%	58.6%	2.0%	28.0%	0.7%	$490,675	39.7%
	Transport by Water	65.0%	11.8%	2.6%	19.6%	0.9%	$53,368	40.6%
	Transport by Other	24.2%	46.9%	2.2%	25.9%	0.7%	$49,327	39.9%
Manufacturing	Food	33.3%	27.2%	16.6%	2.0%	20.9%	$255,506	36.8%
	Beverages and Tobacco	25.8%	21.1%	12.8%	1.6%	38.7%	$75,608	30.7%
	Textile Mills	41.9%	38.4%	12.8%	0.5%	6.3%	$25,574	41.6%
	Textile Product Mills	41.9%	38.4%	12.8%	0.5%	6.3%	$13,529	41.6%
	Apparel	38.1%	34.9%	11.6%	0.5%	14.9%	$32,771	38.9%
	Leather	24.1%	41.2%	13.1%	0.5%	21.2%	$4,641	37.0%
	Lumber and Wood	34.6%	35.4%	16.5%	10.1%	3.5%	$48,957	43.1%
	Paper	53.0%	19.9%	11.4%	8.4%	7.4%	$150,607	41.4%
	Printing and Publishing	44.6%	32.8%	10.8%	2.6%	9.3%	$94,167	40.7%
	Chemicals	30.0%	20.9%	12.1%	1.7%	35.4%	$481,973	32.6%
	Rubber and Plastic	45.1%	24.8%	15.9%	1.4%	12.8%	$102,290	39.7%
	Glass	44.5%	28.6%	12.7%	7.8%	6.4%	$21,692	41.8%
	Cement	44.5%	28.6%	12.7%	7.8%	6.4%	$33,370	41.8%
	Other Nonmetallic Minerals (not including Glass or Cement)	44.5%	28.6%	12.7%	7.8%	6.4%	$27,855	41.8%
	Iron and Steel	51.2%	30.4%	14.0%	3.7%	0.8%	$75,914	43.4%
	Aluminum	49.9%	29.6%	13.6%	3.6%	3.2%	$32,984	42.7%
	Other Primary Metals (not including Iron/Steel or Aluminum)	48.4%	28.7%	13.2%	3.5%	6.2%	$62,647	41.8%
	Fabricated Metal	46.2%	24.9%	16.3%	1.3%	11.3%	$133,914	40.2%
	Machinery	27.9%	20.7%	15.4%	1.1%	34.9%	$136,837	32.9%
	Computer and Elec Equipment	16.1%	12.0%	8.9%	0.6%	62.4%	$383,811	24.1%
	Electronic Equipment	36.0%	26.7%	26.7%	1.5%	9.0%	$277,762	41.3%
	Transportation Equipment (except Motor Vehicles)	16.3%	20.7%	34.0%	1.2%	27.8%	$172,503	35.8%
	Motor Vehicles	28.8%	12.4%	11.2%	0.9%	46.7%	$254,799	29.7%
	Furniture	25.1%	33.2%	23.8%	2.0%	15.9%	$28,633	39.0%
	Miscellaneous	8.3%	8.5%	26.1%	1.5%	55.6%	$96,769	26.9%

Source: Authors' calculations; see text for description of methodology and sources.

Table 7-11. Weighted Average of Fullerton Corporate and Noncorporate METR

Industry in EMPAX-CGE	Percent of Total Capital					Total Capital ($million)	Weighted Average METR
	Equipment	Structures	Inventories	Land	Intangibles		
Agriculture, forestry and fisheries	5.7%	4.7%	9.4%	79.5%	0.7%	$2,330,852	35.6%
Mining	39.2%	48.3%	10.1%	1.7%	0.3%	$75,497	37.3%
Crude petroleum and natural gas	3.7%	88.9%	3.7%	3.4%	0.3%	$268,600	45.0%
Contract construction	24.7%	3.0%	46.6%	24.3%	1.5%	$251,188	43.1%
Food and tobacco	22.1%	17.0%	35.1%	9.4%	16.5%	$228,969	45.2%
Textiles, apparel and leather	27.5%	15.5%	42.3%	9.1%	5.6%	$79,497	46.7%
Paper and printing	39.0%	20.8%	21.7%	11.6%	7.0%	$159,657	42.4%
Petroleum refining	20.2%	34.5%	23.4%	16.0%	5.9%	$124,947	48.9%
Chemicals, rubber and plastics	36.1%	12.3%	23.3%	6.6%	21.7%	$308,453	38.6%
Lumber, furniture, stone, clay and glass	31.0%	22.5%	30.1%	10.0%	6.5%	$111,932	44.1%
Metals, machinery, instruments and misc.	22.9%	13.5%	39.4%	6.4%	17.7%	$1,032,696	44.8%
Transportation equipment	8.7%	9.8%	29.3%	4.8%	47.5%	$194,945	37.8%
Motor vehicles	29.6%	10.1%	27.5%	4.7%	28.2%	$146,399	38.8%
Transportation, communication and utilities	40.3%	45.9%	3.4%	9.8%	0.7%	$1,468,091	40.5%
Trade	10.0%	10.5%	57.1%	18.3%	4.2%	$2,203,818	46.4%
Finance and Insurance	1.4%	49.3%	0.1%	20.8%	28.4%	$352,931	29.5%
Real estate	0.0%	74.7%	0.0%	25.3%	0.0%	$4,669,177	26.3%
Services	37.1%	41.1%	2.4%	11.5%	7.8%	$464,053	29.6%

Source: Fullerton, D., and D. Rogers. 1993. "Who Bears the Lifetime Tax Burden?" Washington, DC: The Brookings Institute.

marginal excess burden (MEB) (see Bovenberg et al. [2003]). MCPF is the cost of raising an additional dollar of government revenue in terms of household income, where government-supplied public goods are separable from household utility. MEB is the same cost assuming that the tax revenue is returned to households in a lump-sum fashion, rather than being spent on public goods. Both measures attempt to quantify efficiency costs associated with taxes (i.e., how taxes have caused consumers to alter their behavior in ways that reduce welfare).

Pioneering CGE work by Bovenberg and Goulder (1996) on interactions between environmental policies and existing tax structures estimates MCPF for PIT as ranging between 1.24 and 1.29. This implies it costs around $1.25 in welfare terms (as measured by Hicksian EV)[13] to raise an additional dollar of government income through the PIT. Distortions associated with corporate taxes are typically higher, but an accepted empirical range is less well established and most literature focuses on income taxes. MEB estimates presented in the CGE literature are generally around 0.3 (measured as the incremental cost of raising taxes and then returning the revenue to households).[14]

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[13]Recall that equivalent variation (EV) is the amount of income that households would take in order to avoid a policy change.

[14]See, for example, Goulder et al. (1999), Goulder, Parry, and Burtraw (1997), Browning (1987), and Ballard et al. (1985).

To estimate MEB in EMPAX-CGE, equal-yield constraints on government income have been included in the model. These equations allow a CGE model to replace an existing tax instrument with an alternative approach that raises the same amount of revenue—or maintains a given level of utility. Following Ballard et al. (1985), the equal-yield constraints in EMPAX-CGE are modeled as ensuring equal purchasing power for the government at the new prices prevailing under the alternative tax policy.[15]

In EMPAX-CGE, the compensated labor-supply elasticity (η_c) is set at 0.40 and the uncompensated labor-supply elasticity (η_{uc}) is set at 0.15, based on estimates used in the other CGE models mentioned above. This implies the elasticity between consumption goods and leisure (σ_{cl}) equals approximately 0.85. Table 7-12 illustrates the MCPF and MEB associated with these assumptions for several types of taxes. These findings are based on all interactions among economic and energy data, tax rates, CES production functions, and production and consumption elasticities in the current structure of EMPAX-CGE (changes in any of these data or assumptions may alter MCPF and MEB estimates).[16]

Table 7-12. MCPF and MEB Estimates in the Dynamic Version of EMPAX-CGE

Tax Instrument	MCPF	MEB
All Taxes	1.22	0.31
Personal Income Taxes	1.23	0.32
Statutory Corporate Taxes	1.32	0.39

[a]MCPF and MEB calculations are based on model runs with a single household in each region to allow comparison of the results to existing estimates in the literature. As noted in Bovenberg and Goulder, the appropriate equilibrium, at which to measure MCPF is a post-policy equilibrium, so MCPF also depends on the policy in question.

[15]This avoids the need to specify a utility function for the government and limits the number of utility-maximizing agents in the model (which simplifies results interpretation).

[16]As noted in Bovenberg and Goulder, the appropriate equilibrium at which to measure MCPF is a post-policy equilibrium, so MCPF also depends on the policy in question.

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APPENDIX A
FEATURES OF SELECTED CGE MODELS

Several CGE models have been applied to economic analyses of environmental and natural resource issues. To illustrate key similarities and differences among models, we review general features of EMPAX-CGE and two other CGE models of particular interest to EPA (see Table A-1):[1]

- Jorgenson/Ho/Wilcoxen Inter-temporal General Equilibrium Model (IGEM)[2]
- Argonne Multi-sector Industry Growth Assessment Model (AMIGA)[3]

Two of the models, EMPAX-CGE and IGEM, are single-country models of the U.S. economy (all other countries combined into a single "rest-of-world" category that characterizes international trade). AMIGA includes the United States along with other countries. EMPAX-CGE divides the United States into five regions, providing it with the capability to assess policy impacts at the subnational level, while IGEM and AMIGA represent the United States as a single region. The static version of EMPAX-CGE defines 10 regions approximating NERC regions, and the dynamic version has 5 regions. IGEM includes 35 sectors, and AMIGA has over 200. The number of industries included in EMPAX-CGE varies: the national static version has 384 sectors, the regional static version includes 40 sectors, and the regional dynamic version has 17 sectors. EMPAX-CGE and AMIGA are considered calibrated models, that is, they use a set of parameters to replicate a benchmark data set as a model solution and impose any necessary substitution elasticities on the model (the EMPAX-CGE elasticities come from MIT's EPPA model).[4] In contrast, IGEM econometrically estimates utility and cost function elasticities.

All three models offer different approaches to modeling sector detail for the energy industry and household responses to policies. The dynamic version of EMPAX-CGE includes six aggregate energy industries (coal, crude oil extraction, electric generation [fossil and nonfossil], natural gas, refined petroleum; in the static version of EMPAX-CGE the refining sector produces three types of oil). EMPAX-CGE and IGEM also offer the capability of being linked with a detailed electric power generation model, the Integrated Planning Model or IPM.[5] Similar to EMPAX-CGE, IGEM includes five aggregate energy sectors (coal, crude oil,

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[1]For additional information on CGE models used for analyses of environmental and natural resource issues, see U.S. Environmental Protection Agency. 2003. "OAQPS Economic Analysis Resource Document." Office of Air Quality Planning and Standards, Innovative Strategies and Economics Group.

[2]See http://www.ksg.harvard.edu/cbg/ptep/IGEM.htm for information on IGEM.

[3]See http://amiga.dis.anl.gov for information on AMIGA.

[4]See http://web.mit.edu/globalchange/www/eppa.html for information on EPPA.

[5]See http://www.epa.gov/airmarkt/epa-ipm/ for information on IPM.

electricity, natural gas, and refined petroleum) but does not distinguish between types of electricity generation. AMIGA includes a "bottom up" characterization of the energy industry with emphasis on supply technology choices. The AMIGA characterization includes an electric generation model with associated unit inventory. EMPAX-CGE includes several representative households in each region, whose responses to policies are endogenous and can influence model decisions. IGEM uses a single representative household when solving the model, but applies a numerical procedure post-solve to estimate impacts for over 16,800 household types. AMIGA has a household demand module with a single representative household.

The dynamic version of EMPAX-CGE, IGEM, and AMIGA are all multiperiod models and consider dynamic effects of policies. The dynamic version of EMPAX-CGE and IGEM are intertemporal CGE models with forward-looking producers and consumers who have perfect foresight. The AMIGA model considers multiperiod investment decisions but does not assume perfect foresight. EMPAX-CGE, IGEM, and AMIGA include standard impact measures of macroeconomic variables such as GDP, consumption, investment, and employment. All three also provide output, price, and employment impacts by sector. EMPAX-CGE and IGEM provide measures of changes in household welfare (using equivalent variation) from consumption of goods and leisure, and AMIGA calculates utility from consumption of goods. They all also include taxes. EMPAX-CGE and IGEM include a labor-leisure decision, which allows evaluation of tax distortions, but AMIGA does not.

Each model uses a different specification of pollution control costs. EMPAX-CGE determines how pollution abatement expenditures are spread across different types of purchases using data from the Nestor and Pasurka study. This information provides details on pollution abatement expenditures by 41 types of industries and includes labor and capital expenditures associated with pollution control, as well as necessary materials inputs. In contrast, IGEM's approach assumes that pollution abatement expenditures scale up existing production costs by the same mix of inputs as currently used in production (i.e., a Hicks neutral cost increase). AMIGA's model includes information on new pollution control technologies, and the model specifies associated inputs demands for employing these technologies.

GE feedbacks associated with environmental quality changes are considered to some extent in these models. Although all three models can consider roles of environmental improvements in their production frameworks (i.e., increases in labor productivity), none of the models consider effects of environmental changes on household preferences.[6]

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[6]This characteristic is not restricted to these models, but applies to many CGE models used for policy evaluation (Espinoza and Smith, 1995).

Table A-1. Selected Features of IGEM, AMIGA and EMPAX-CGE Models

Characteristic	IGEM	AMIGA	EMPAX-CGE (dynamic version)
Geographic/ Sectoral Scope	Single country (U.S.) model with one region and 35 sectors	Multi-country model with a single region in U.S. and over 200 industries	Single country (U.S.) model with 5 regions and 17 sectors
Calibration/ Estimation	Econometrically estimated	Calibrated	Calibrated (MIT estimates)
Energy Sector	Five energy sectors (coal, crude oil, electricity, natural gas, refined petroleum); can be linked to detailed electric power generation model	Detailed energy market specification with technology choices. Includes electric generation model with unit inventory	Six energy sectors (coal, crude oil, electric generation [fossil and nonfossil], natural gas, refined petroleum); can be linked to detailed electric power generation model
Households	Uses a numerical procedure to estimate impacts for over 16,000 different household types, based on U.S. effects	Single representative household	Four representative households per region based on income (total of 20); solved for simultaneously with policy impacts
Dynamic Modeling	Intertemporal optimization, forward looking agents; perfect foresight	No perfect foresight, agents act on approximate intertemporal rules	Intertemporal optimization, forward looking agents; perfect foresight
Capital Mobility and Investment	Perfectly malleable and mobile capital	Putty-(semi)Clay structure	Perfectly malleable capital; quadratic adjustment costs control installation costs for new capital
Technology Change	Modeled through substitution of production inputs. Also has endogenous technological change	Models explicit technologies that can be adopted.	Modeled through substitution of production inputs. Could include additional options
Taxes	Yes (has labor-leisure choice)	Yes (no labor-leisure choice)	Yes (has labor-leisure choice)
Natural Resources	Includes natural resource sectors	Includes natural resource sectors	Resource prices matched to AEO forecasts. MIT resource supply elasticities set around price path.
Specification of Pollution Abatement Costs	Pollution abatement input mix mirrors output production function	Focuses on new pollution control technologies and specifies associated sector input demands	Distributes pollution abatement expenditures using an input-output matrix of these expenditures
Feedbacks Associated with Environmental Quality Changes	Can consider exogenous changes in labor productivity associated with environmental quality changes	Can consider exogenous changes in labor productivity associated with environmental quality changes	Can consider exogenous changes in labor productivity associated with environmental quality changes
Examples of Impact Measures	Macroeconomic variables such as GDP, consumption, investment, and employment; output, price and employment by sector; equivalent variation welfare changes	Macroeconomic variables such as GDP, consumption, investment, and employment. Output, price and employment by sector, household utility	Macroeconomic impacts such as GDP, consumption, investment, and employment; output, price and employment by region and sector; equivalent variation welfare changes

APPENDIX B
LINKAGE BETWEEN EMPAX-CGE AND THE INTEGRATED PLANNING MODEL

EMPAX-CGE can be used to analyze a wide array of policy issues, including analyses of the economic costs of environmental regulations, distributional effects of policies across different industries and regions of the United States, and the effects of energy efficiency improvements, among many other possibilities. It is capable of estimating how a change in a single part (or multiple parts) of the economy will influence firms and consumers across the United States. However, although CGE models have been used extensively to analyze climate policies that limit carbon emissions from electricity production,[1] some other types of utility-emissions policies are more difficult to consider. Unlike carbon dioxide, emissions of pollutants such as SO_2, NO_x, and mercury are not necessarily proportional to fuel use.

These types of emissions can be lowered by a variety of methods: fuel switching from high- to low-sulfur coal, moving from coal- to gas-fired generation, and/or installing retrofit equipment designed to reduce emissions. However, the boiler-specific nature of these decisions, and their costs and effects, cannot be adequately captured by the more general structure of a CGE model. In addition, because of the ways that retrofits and construction of new generating units affect electricity prices and fuel use, a detailed characterization of electricity markets is preferable when estimating implications of policies. For these reasons, an interface has been developed that allows a linkage between EMPAX-CGE and the Integrated Planning Model (IPM)[2] used by EPA.

IPM is a comprehensive model of electricity generation and transmission in the United States. The model contains data on all generating units available to dispatch electricity to the national grid, their existing equipment configurations and fuel consumption, transmission constraints, and generating costs. It includes characteristics of new units and retrofits that can be built and/or installed. IPM is capable of estimating how electric utilities will respond to policies by determining the least-cost methods of generating sufficient electricity to meet demands, while meeting emissions reduction (and other) objectives.

However, IPM does not fully consider how changes in the electricity sector, or electricity prices, will affect the rest of the U.S. economy. Combining the strengths of IPM (disaggregated unit-level analyses of electricity policies) with the strengths of CGE models (macroeconomic effects of environmental policies) allows investigation of economy-wide implications of policies that would normally be hard to estimate consistently and effectively. For electricity-generation

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[1]See, for example, the analyses of energy/climate using CGE models organized by the Stanford University Energy Modeling Forum (http://www.stanford.edu/group/EMF/home/index.htm).
[2]See http://www.epa.gov/airmarkt/epa-ipm/ for complete IPM documentation.

regulations that require a very disaggregated level of analysis, IPM can determine for EMPAX-CGE a number of electricity market outcomes needed to evaluate macroeconomic implications of policies. The linkage with IPM then allows EMPAX-CGE to take these findings and use them in "counterfactual" policy evaluations. Results from EMPAX-CGE on variables like electricity demand, or changes in energy markets outside of the electricity sector, could also be passed back to IPM to inform its modeling (to date, this step in the process has not been implemented).

Among the many results provided by IPM, several can potentially have significant implications for the rest of the economy including changes in electricity prices, fuel consumption by utilities, fuel prices, and changes in electricity production expenditures. EMPAX-CGE is capable of simultaneously incorporating some or all of these IPM findings, depending on the desired type and degree of linkage between the two models. At the regional level, EMPAX-CGE can match changes estimated by IPM for the following variables:

- electricity prices (percentage change in retail prices)
- coal and gas consumption for electricity (percentage changes in BTUs)
- coal and gas prices (percentage changes in prices)
- coal and gas expenditures ($ changes—BTUs of energy input times $/MMBTU)
- capital costs ($ changes)
- fixed operating costs ($ changes)
- variable operating costs ($ changes)

In addition, EMPAX-CGE can control electricity output to simulate the fixed demand used by IPM, or it can determine how changes in electricity prices will affect demand for electricity and hence electricity generation levels.

The IPM model calculates these variables for 26 NERC subregions. EMPAX-CGE uses information on generation levels for these subregions to aggregate the IPM results into the 10 regions used in the static CGE model and the five regions used in the dynamic CGE model. Electricity prices paid by firms and consumers are then matched to the changes shown by IPM. Fuel consumption by utilities in physical units (Btus) is adjusted by the percentage changes in the IPM results. Fuel prices paid by both industries and households are also changed by the amounts estimated by IPM (the coal and gas market modules of IPM cover all fuel consumers, not merely utilities, so prices paid by all agents in EMPAX-CGE are adjusted).

In addition to energy market effects, IPM provides information on generation costs in terms of capital costs, fixed operating costs, and variable operating costs. For EMPAX-CGE to effectively incorporate these IPM data on changes in costs, they have to be expressed in terms of the productive inputs used in CGE models (i.e., capital, labor, and material inputs produced by other industries). Rather than assume these costs represent a proportional scaling up of all inputs to the electricity industry in EMPAX-CGE, we use Nestor and Pasurka (1995) data on purchases made by industries for environmental protection reasons to allocate these additional expenditures across inputs within EMPAX-CGE (discussed in Chapter 5). Once these expenditures are specified, the incremental costs from IPM can be used to adjust the production technologies and input purchases by electricity generation in the CGE model.

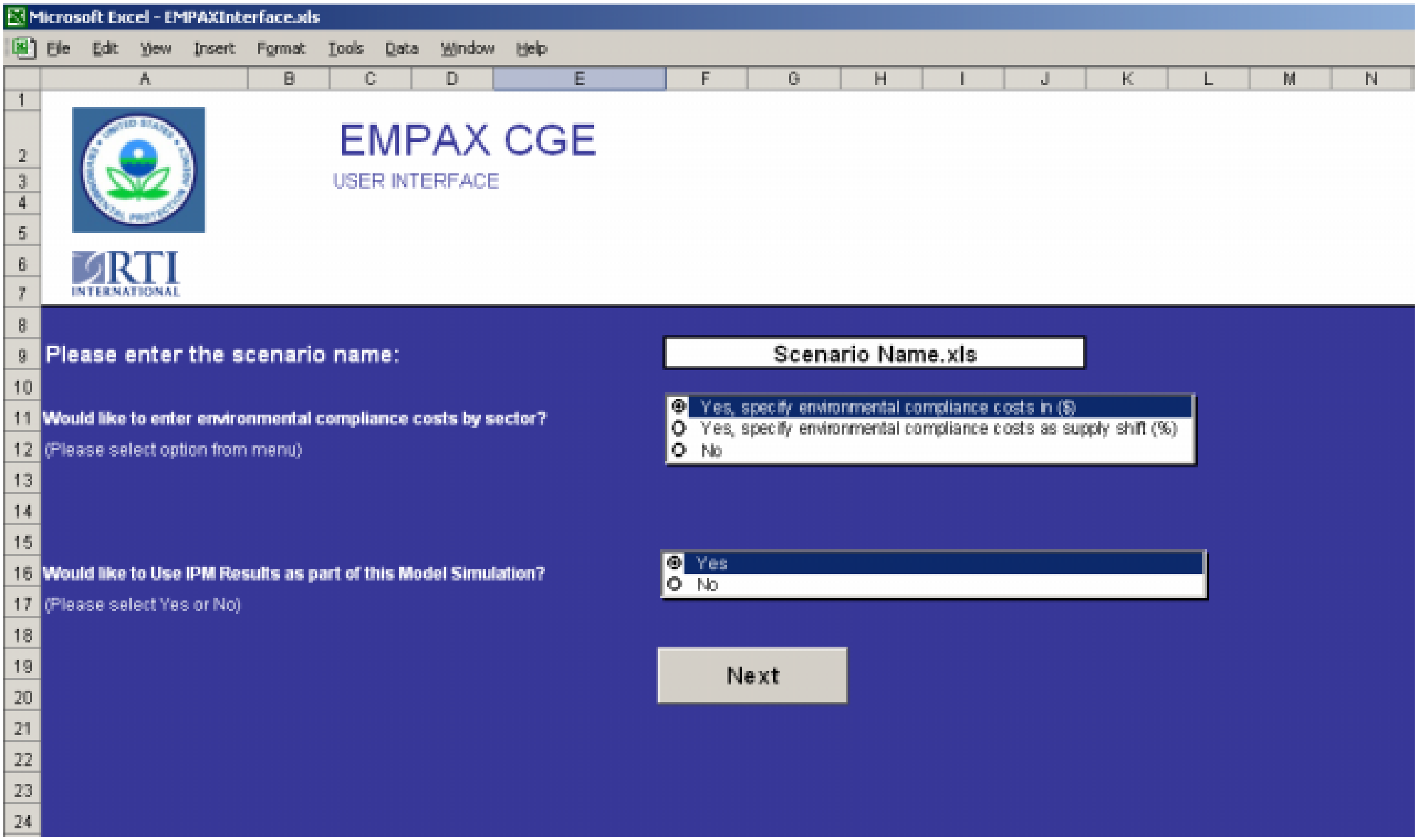
By providing electricity market findings for policies where disaggregated unit-level characteristics affect policy results and extending them to the rest of the economy, the linkage between IPM and EMPAX-CGE allows the two models to consider policies that could not be readily modeled by either type of model individually. For example, using the IPM conclusions, EMPAX-CGE can conducted detailed examinations of policy implications such as:

- how changes in electricity prices will affect industries' decisions on fuel choice and energy-efficiency improvements;
- how changes in electricity prices will influence household demand for electricity, other types of fuel, and consumption goods;
- how changes in fuel consumption by utilities will alter fuel markets (prices and production levels);
- how changes in fuel prices affect industrial and household demand for fuels;
- how changes in energy prices will alter production costs for industries and affect commodity prices;
- how increased capital needs by utilities may affect the rest of the economy by crowding out capital investments originally directed towards other industries and raising capital prices;
- how use of additional labor and materials by utilities may draw resources away from other industries; and
- how changes in electricity-generation technology will alter input prices and production costs for other industries.

An automated Excel interface has been developed for EMPAX-CGE that allows a user run the model and specify what types of information it should consider. This interface guides the user through selection of a scenario, types of costs and other data to be included, what results from IPM to incorporate, imports the data, runs the model, and produces an Excel file with scenario results.

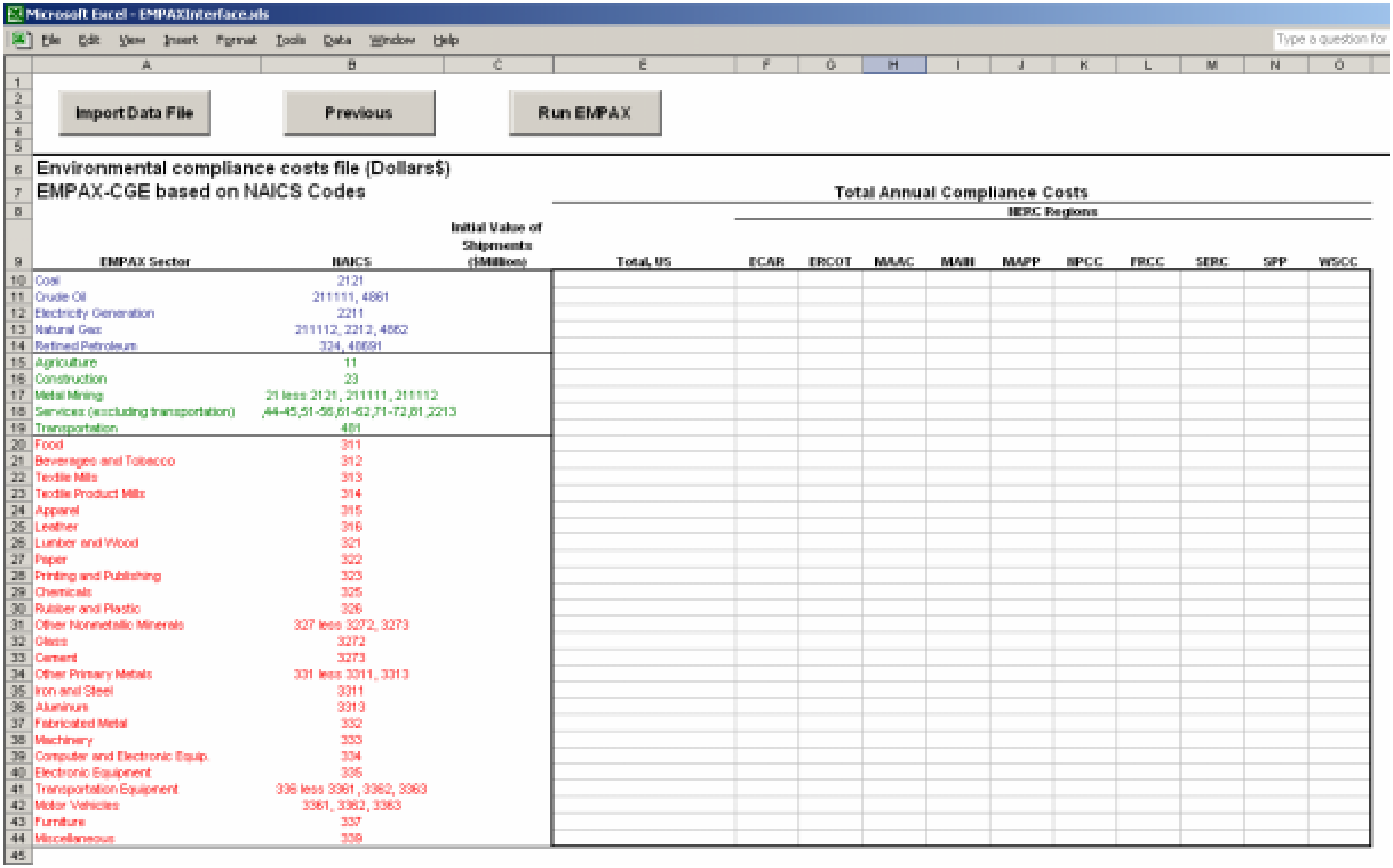
The main screen of the EMPAX-CGE User Interface is shown in Figure B-1. It prompts the user for a scenario name and then inquires whether the user is interested in specifying compliance costs for particular sectors in either dollar or percentage terms, and also whether information from IPM will be used. Based on these selections, the user is directed to the screens shown in Figures B-2 and/or B-3.

Figure B-1. EMPAX-CGE User Interface



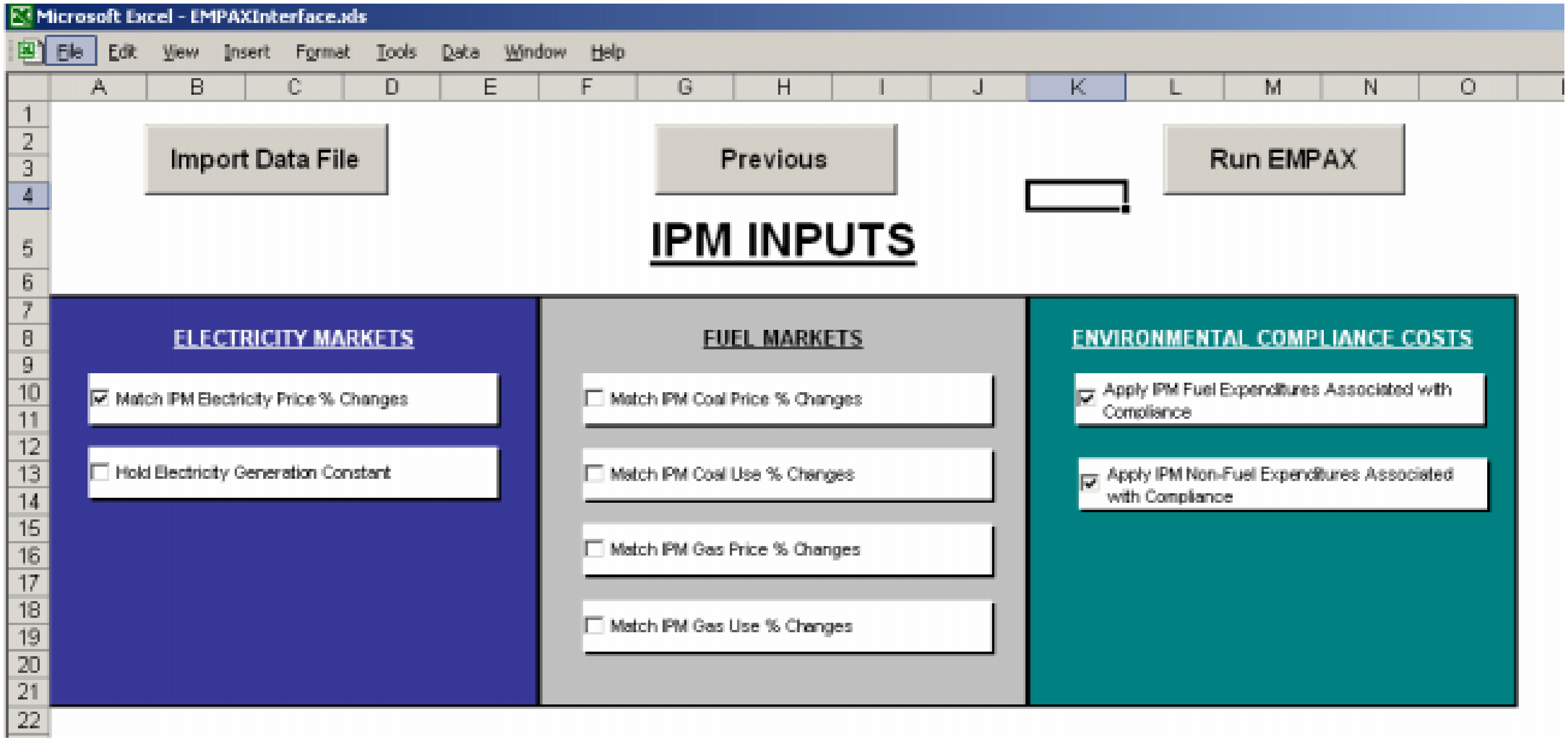
The screen shown in Figure B-2 allows the user to enter compliance costs for sectors in EMPAX-CGE in dollar terms (a similar screen is available for percentage cost increases). This allows EMPAX-CGE to incorporate costs coming from detailed models such as AirControlNet. Data from pre-formatted files generated by AirControlNet can be imported, or the user can enter data in the table. Nestor and Pasurka data are used to allocate these costs to appropriate input purchases by industries.

Figure B-2. Interface Screen to Import Compliance Costs in Dollar Terms



The screen shown in Figure B-3 allows the user to import IPM results from a pre-formatted file. There are also a wide range of choices on how the IPM information is used. By selecting particular options (for example, matching IPM's changes in electricity prices), the user can determine how the model will use the IPM data and which types of IPM results will be matched in EMPAX-CGE.

Figure B-3. Interface Options to Specify How IPM Inputs are Used



APPENDIX C

LIST OF INDUSTRIES IN THE NATIONAL STATIC VERSION OF EMPAX-CGE

Table C-1. Industries that Are Identical Between National and Regional Static Versions

Industry	
Energy (6)	
Coal	
Crude Oil	
Electricity *(fossil and nonfossil)*	**Same as in 40-sector EMPAX-CGE**
Natural Gas	
Petroleum	
Nonmanufacturing (9)	
Agriculture	
Construction	
Mining	
Services	
Transport by Air	**Same as in 40-sector EMPAX-CGE**
Transport by Freight Truck	
Transport by Railroad	
Transport by Water	
Transport by Other	
EMPAX Energy-Intensive Industries from the Regional Static Version (3)	
Cement	**Same as in 40-sector EMPAX-CGE**
Glass Products	
Motor Vehicles	

Table C-2. List of Disaggregated Manufacturing Industries in National Static Version

Meat Packing Plants	Coated Fabrics Not Rubberized	Manifold Business Forms	Asbestos Products
Sausages And Other Prepared Meats	Tire Cord And Fabric	Greeting Card Publishing	Minerals Ground Or Treated
Poultry Processing	Nonwoven Fabrics	Blankbooks And Looseleaf Binders	Mineral Wool
Creamery Butter	Cordage And Twine	Bookbinding & Related	Nonclay Refractories
Cheese Natural And Processed	Textile Goods N.E.C	Typesetting	Nonmetallic Mineral Products N.E.C
Condensed And Evaporated Milk	Apparel Made From Purchased Material	Plate Making	Blast Furnaces And Steel Mills
Ice Cream And Frozen Desserts	Curtains And Draperies	Alkalies & Chlorine	Electrometallurgical Products
Fluid Milk	Housefurnishings N.E.C	Industrial Gases	Steel Wire And Related Products
Canned Specialties	Textile Bags	Inorganic Pigments	Cold Finishing Of Steel Shapes
Canned Fruits And Vegetables	Canvas Products	Inorganic Chemicals Nec.	Steel Pipe And Tubes
Dehydrated Food Products	Pleating And Stitching	Cyclic Crudes Interm. & Indus. Org	Iron And Steel Foundries
Pickles Sauces And Salad Dressing	Automotive And Apparel Trimming	Plastics Materials And Resins	Primary Copper
Frozen Fruits Juices And Vegetable	Schiffi Machine Embroideries	Synthetic Rubber	Primary Aluminum
Frozen Specialties	Fabricated Textile Products N.E.C.	Cellulosic Man-made Fibers	Primary Nonferrous Metals N.E.C.
Flour And Other Grain Mill Products	Logging Camps And Logging Contracto	Organic Fibers Noncellulosic	Secondary Nonferrous Metals
Cereal Preparations	Sawmills And Planing Mills General	Drugs	Copper Rolling And Drawing
Rice Milling	Hardwood Dimension And Flooring Mil	Soap And Other Detergents	Aluminum Rolling And Drawing
Blended And Prepared Flour	Special Product Sawmills N.E.C	Polishes And Sanitation Goods	Nonferrous Rolling And Drawing N.E
Wet Corn Milling	Millwork	Surface Active Agents	Nonferrous Wire Drawing And Insulat
Dog Cat And Other Pet Food	Wood Kitchen Cabinets	Toilet Preparations	Aluminum Foundries
Prepared Feeds N.E.C	Veneer And Plywood	Paints And Allied Products	Brass Bronze And Copper Foundries
Bread Cake And Related Products	Structural Wood Members N.E.C	Gum And Wood Chemicals	Nonferrous Castings N.E.C.
Cookies And Crackers	Wood Containers	Nitrogenous And Phosphatic Fertaliz	Metal Heat Treating
Sugar	Wood Pallets And Skids	Fertilizers Mixing Only	Primary Metal Products N.E.C.
Confectionery Products	Mobile Homes	Agricultural Chemicals N.E.C.	Metal Cans
Chocolate And Cocoa Products	Prefabricated Wood Buildings	Adhesives And Sealants	Metal Barrels Drums And Pails
Chewing Gum	Wood Preserving	Explosives	Cutlery
Salted And Roasted Nuts & Seeds	Reconstituted Wood Products	Printing Ink	Hand And Edge Tools N.E.C.
Cottonseed Oil Mills	Wood Products N.E.C	Carbon Black	Hand Saws And Saw Blades
Soybean Oil Mills	Wood Household Furniture	Chemical Preparations N.E.C	Hardware N.E.C.
Vegetable Oil Mills N.E.C	Upholstered Household Furniture	Tires And Inner Tubes	Metal Sanitary Ware
Animal And Marine Fats And Oils	Metal Household Furniture	Rubber And Plastics Footwear	Plumbing Fixture Fittings And Trim
Shortening And Cooking Oils	Mattresses And Bedsprings	Rubber And Plastics Hose And Beltin	Heating Equipment Except Electric
Malt Beverages	Wood Tv And Radio Cabinets	Gaskets Packing And Sealing Device	Fabricated Structural Metal
Malt	Household Furniture N.E.C	Fabricated Rubber Products N.E.C.	Metal Doors Sash And Trim
Wines Brandy And Brandy Spirits	Wood Office Furniture	Miscellaneous Plastics Products	Fabricated Plate Work -- Boiler Shops
Distilled Liquor Except Brandy	Metal Office Furniture	Leather Tanning And Finishing	Sheet Metal Work
Bottled And Canned Soft Drinks	Public Building Furniture	Footwear Cut Stock	Architectural Metal Work
Flavoring Extracts And Syrups N.E.	Wood Partitions And Fixtures	House Slippers	Prefabricated Metal Buildings
Canned And Cured Sea Foods	Metal Partitions And Fixtures	Shoes Except Rubber	Miscellaneous Metal Work
Prepared Fresh Or Frozen Fish Or Se	Blinds Shades And Drapery Hardwar	Leather Gloves And Mittens	Screw Machine Products And Bolt Et
Roasted Coffee	Furniture And Fixtures N.E.C	Luggage	Iron And Steel Forgings
Potato Chips & Similar Snacks	Pulp Mills	Womens Handbags And Purses	Nonferrous Forgings
Manufactured Ice	Paper Mills Except Building Paper	Personal Leather Goods	Automotive Stampings
Macaroni And Spaghetti	Paperboard Mills	Leather Goods N.E.C	Crowns And Closures
Food Preparations N.E.C	Paperboard Containers And Boxes	Brick And Structural Clay Tile	Metal Stampings N.E.C.
Cigarettes	Paper Coated & Laminated Packaging	Ceramic Wall And Floor Tile	Plating And Polishing
Cigars	Paper Coated & Laminated N.E.C.	Clay Refractories	Metal Coating And Allied Services
Chewing And Smoking Tobacco	Bags Plastic	Structural Clay Products N.E.C	Small Arms Ammunition
Tobacco Stemming And Redrying	Bags Paper	Vitreous Plumbing Fixtures	Ammunition Except For Small Arms
Broadwoven Fabric Mills And Finishi	Die-cut Paper And Board	Vitreous China Food Utensils	Small Arms
Narrow Fabric Mills	Sanitary Paper Products	Fine Earthenware Food Utensils	Other Ordnance And Accessories
Womens Hosiery Except Socks	Envelopes	Porcelain Electrical Supplies	Industrial And Fluid Valves
Hosiery N.E.C	Stationery Products	Pottery Products N.E.C	Steel Springs Except Wire
Knit Outerwear Mills	Converted Paper Products N.E.C	Concrete Block And Brick	Pipe Valves And Pipe Fittings
Knit Underwear Mills	Newspapers	Concrete Products N.E.C	Miscellaneous Fabricated Wire Produ
Knit Fabric Mills	Periodicals	Ready-mixed Concrete	Metal Foil And Leaf
Knitting Mills N.E.C	Book Publishing	Lime	Fabricated Metal Products N.E.C.
Yarn Mills And Finishing Of Textile	Book Printing	Gypsum Products	Steam Engines And Turbines
Carpets And Rugs	Miscellaneous Publishing	Cut Stone And Stone Products	Internal Combustion Engines N.E.C.
Thread Mills	Commercial Printing	Abrasive Products	Farm Machinery And Equipment