

# **Economy-Wide Modeling: Evaluating the Economic Impacts of Air Regulations**

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Prepared for the U.S. EPA Science Advisory Board Panel (SAB) on Economy-Wide Modeling of the Benefits and Costs of Environmental Regulation

This paper has been developed to inform the deliberations of the SAB Panel on the technical merits and challenges of economy-wide modeling for an air regulation. It is not an official U.S. Environmental Protection Agency (EPA) report nor does it necessarily represent official policies or views of the U.S. EPA.

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## 1. Introduction

A benefit-cost analysis (BCA) that quantifies the social benefits and costs associated with a regulation is mainly focused on evaluating the efficiency or cost-effectiveness of a proposed regulation. In this context, the correct measure for gauging a regulation's effect on an individual or household is the net-change in economic welfare that they experience. However, also of keen interest to policymakers and the public are how different segments of the economy are affected by the regulation, which EPA analyzes separately from the BCA in an economic impact analysis (EIA).<sup>1</sup>

According to EPA's *Guidelines for Preparing Economic Analyses* (Economic Guidelines), an EIA identifies the sectors of the economy that benefit from or are harmed by a policy, and then estimates the magnitude of those gains and losses (U.S. EPA, 2010a). They may be expressed using a variety of metrics including changes in profitability, employment, prices, government revenues or expenditures, and trade balances, among others. The sectors of the economy affected by a proposed regulation may be defined broadly (e.g., industry, government, and households) or narrowly (e.g., a particular industry sector, affected small businesses, consumers within a particular income category, or a geographic region).

While a BCA attempts to quantify net changes in overall societal welfare due to a policy change, an EIA's main focus is on the costs and benefits that accrue to subsets of individuals or entities in the private market. Certain types of payments, for example the taxes paid on additional fuel or a required piece of pollution control equipment, are not included when estimating the social costs of a proposed policy (i.e., they net out of the calculation since they are a transfer from one part of the economy to another)<sup>2</sup> but are relevant when evaluating the private costs faced by a firm and therefore included in an EIA. Despite these differences, good economic practice dictates that the BCA and EIA developed in support of a rulemaking are consistent with each other (e.g., use the same baseline, key assumptions, measures of engineering or direct compliance costs).

This paper serves two purposes. The first half of the paper describes the types of economic impacts that are typically of interest to policymakers when proposing or finalizing an air regulation. In this context the first half of the paper describes when CGE models have - or have not - been used by EPA to evaluate a subset of these economic impacts. It also describes the main economy-wide approaches used by outside organizations to analyze EPA air regulations, as well as metrics used to describe employment impacts.

The second half of the paper focuses on what EPA might learn from the academic literature with regard to key features and methods in U.S. CGE models for analyzing economic impacts of an air regulation. In particular, the second half of the paper focuses on CGE approaches that show potential for capturing short and long run responses in labor and capital markets, sectoral impacts, changes in energy prices,

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<sup>1</sup> While, "in principle, both [efficiency and economic impacts] could be estimated simultaneously using a general equilibrium model, in practice ... they are usually estimated separately" (U.S. EPA, 2010a).

<sup>2</sup> "Transfer payments are monetary payments from one group to another that do not affect total resources available to society" (OMB, 2003).

and differentiated effects on households by income. It also describes other (non-CGE) economy-wide modeling approaches used in the academic literature to analyze economic impacts, when applicable.

## 2. Measuring Economic Impacts and the Role of CGE Modeling at EPA

Table 1 briefly describes the broad array of economic impact categories highlighted in EPA's Economic Guidelines. While our main emphasis in this section of the paper is to describe the extent to which CGE models have been used by EPA to evaluate the impact categories explicitly highlighted in the charge (i.e., changes in labor and capital markets, energy price impacts, sectoral impacts, and how effects are distributed across households on the basis of income), this longer list provides context regarding the types of impacts that EPA often evaluates for air quality regulations. Estimation of some of these impacts are required by federal statute or Executive Order. For instance, Executive Order 13563 states: "Our regulatory system must protect public health, welfare, safety, and our environment while promoting economic growth, innovation, competitiveness, and job creation. It must be based on the best available science." Executive Order 13211 requires, to the extent permitted by law, that Agencies prepare a statement of energy effects when a regulatory action is expected to significantly affect energy supply, distribution, or use.<sup>3</sup>

Measures of compliance costs often are used to characterize the net cost burden of regulation on directly affected firms (after accounting for taxes and relevant transfers), assuming that none of the costs are passed onto consumers. When, instead, one assumes that compliance costs are passed through in their entirety as higher prices, they can be used to characterize the net cost burden on consumers. If reality falls between these two extremes, then a model that incorporates demand and supply elasticities can help determine the relative burden of the regulation on directly regulated sectors, consumers, and producers in other markets that rely on the regulated good as an input to production. Incorporation of related markets becomes important if one expects consumers/other producers to not just reduce consumption of the goods produced by the regulated sector but also to substitute away from them. Likewise, the implications of the regulation for employment and wages in the regulated sector may depend on the degree to which any costs not passed onto consumers are absorbed by firms.

To describe the complete incidence of a regulation, one would need to consider the distribution of both costs and benefits. However, folding benefits into the evaluation of economic impacts is complicated. An analyst would need to understand to what extent certain types of households differentially benefit from reductions in emissions. Another important consideration would be whether workers enjoy health improvements that enhance their productivity, thus reducing the long-term impact of the regulation on producers and labor. In practice, as is true of BCA, the evaluation of how costs and benefits are distributed across economic sectors are usually evaluated separately. The main focus of this white paper is on the use of economy-wide approaches for evaluating the distribution of costs.

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<sup>3</sup> See EPA's Economic Guidelines for a more detailed list of statutes and Executive Orders related to the analysis of economic impacts (U.S. EPA, 2010a).

**Table 1: Types of Economic Impacts Described in EPA’s Economic Guidelines**

Type of Economic Impacts	Description
Sectoral effects, firm profitability	Effects on prices and quantities in the regulated and other related sectors; degree of cost pass through and reaction of consumers and producers to price changes will determine effects on profitability.
Plant closures	Potential for plant shutdown. When evaluating the potential for plant closures, it is important to consider whether production shifts to other operating facilities.
Small business effects	What entities constitute a small business is defined by the Small Business Administration. Analyses are conducted to identify whether a rule has a significant impact on a substantial number of small entities (SISNOSE).
Industry competitiveness effects	Whether regulation results in barriers to entry for new firms or enhances market power, which reduces economic efficiency in the market.
Energy supply, distribution and prices	Energy market effects of key interest include effects on oil supply and fuel production, changes in coal and natural gas production and use, changes in the cost of producing electricity and effects on energy prices.
Employment	Net employment impacts from environmental regulation are difficult to disentangle from changes driven by other economic factors, and are a mix of potential declines and gains in different sectors, regions, and over time. Regulated firm-level impacts on labor demand can be decomposed into an output effect (changes in output lead to changes in factor inputs) and a substitution effect (holding output constant, labor-intensity may also change). As output and substitution effects may be positive or negative, economic theory alone cannot predict the direction of the net firm-level impact. Labor supply may also be affected.
Consumers	This includes the burden on households of regulation-induced price impacts, sometimes on basis of income, and the distribution of health-related benefits. <sup>4</sup> Consideration of the availability of substitutes and the ability of households to switch to them should also be taken into account.
Economic growth and technical efficiency	May be difficult to observe and often not quantified. Effects on technical efficiency are challenging to analyze because one needs to evaluate degree to which regulation-induced price changes cause firms to use less than efficient production techniques.
Governments and non-profits	Whether an organization can afford regulatory requirements (e.g., effect on debt and financial health), additional hour burdens (e.g., to implement monitoring and enforcement requirements), or changes in tax revenues. Effects on small entities (e.g., small governments) also need to be separately considered.

<sup>4</sup> Analyses of potential environmental justice (EJ) concerns typically examine the distribution of environmental quality and human health risks across minority populations, low-income populations, and indigenous populations, which are often not monetized. We do not discuss the analysis of potential EJ concerns in this white paper. EPA has separate guidance on this topic, also reviewed by the Science Advisory Board (see U.S. EPA, 2016).

Both the ability of EPA to quantify economic impacts of an air regulation and the models available to appropriately quantify them will vary. When economic impacts outside of the regulated sector are not expected to be significant, a partial equilibrium (PE) approach may be sufficient. However, when many sectors are expected to experience significant impacts due to the regulation a focus only on effects in the directly regulated sector may miss important economic impacts that occur in other sectors of the economy. As previously discussed in the “Economy-Wide Modeling: Social Cost and Welfare” white paper (social cost white paper), the more interconnected a regulated sector is with the rest of the economy, the greater the likelihood that a regulation will affect related markets.

CGE models are “particularly effective in assessing resource allocation and welfare effects. These effects include the allocation of resources across sectors (e.g., employment by sector), the distribution of output by sector, the distribution of income among factors, and the distribution of welfare across different consumer groups, regions and countries” (US EPA 2010a). As discussed in the “Economy-Wide Modeling: Benefits of Air Quality Improvements” white paper (benefits white paper), relatively few CGE models have incorporated benefits to date.

While Table 2 shows that EPA has used CGE models to evaluate aspects of many of the listed impact categories, they have been used relatively sparingly by EPA to evaluate the economic impacts of particular air regulations. A key consideration is the level of disaggregation that can be defensibly supported by the data and modeling approach utilized. In the context of a particular rulemaking, EPA typically relies on qualitative, engineering, or PE approaches to evaluate economic impacts in many categories due to the need for a relatively high level of sectoral detail not available in most CGE models (e.g., statutes may require EPA to distinguish by type of firm - small businesses or non-profits - or consumer - by income or sociodemographic characteristics). In specific instances, CGE models have been used, in combination with other analytic approaches, to evaluate sectoral effects, energy supply and energy prices, long run changes in the labor market, and effects on consumers. Section 3.1 describes these instances in greater detail.

It is also important to keep in mind that many CGE models are not designed to shed light on certain types of impacts included in Table 2. For example, a forward looking CGE model that assumes full employment and instantaneous adjustment of markets to a shock, is likely ill-suited to evaluate the potential for short term adjustments in labor and capital markets, or shortages of certain types of specialized equipment or expertise in particular markets as they adjust to a new regulation.

**Table 2: Current EPA Practice and CGE Capabilities by Economic Impact Category**

<b>Type of Economic Impact</b>	<b>Current Practice for Analysis of EPA Air Quality Regulations</b>	<b>Degree Typical CGE Model Accounts for Economic Impact</b>
Sectoral effects, profitability	Partial or general equilibrium models have been used to characterize changes in prices and quantities; engineering or PE models often used to evaluate detailed sectoral changes	Most CGE models have fairly aggregate sectors (e.g. coal generation, primary metals) that limit ability to evaluate detailed effects, and typically assume costs are fully passed through to consumers in long-run (LR)
Plant closure, small business, industry competitiveness effects	Typically use engineering or PE approach; for small business effects often compare compliance costs to sales or revenues	Short-run (SR) implications and disaggregation of effects by firm size not available in CGE; ability to account for market power in CGE also limited
Energy supply, distribution and prices	Detailed sector model often used for larger rules. CGE models linked with the energy sector model have been used to analyze how changes in the composition of fuel supply propagate through the economy	Most CGE models have some level of detail on the energy sector, though it is fairly aggregate; some have one-way or iteratively link with detailed energy sector models to provide greater detail on capacity and fuel changes
Employment	Typically qualitative or partial quantification of impacts in the regulated, environmental protection, and some directly-related sectors using engineering-cost estimates; CGE models rarely used to evaluate LR changes to labor-leisure tradeoffs and wages	CGE models can evaluate LR changes to wages and labor-leisure tradeoffs under full employment; involuntary unemployment is typically not modeled; alternative treatments of employment to account for adjustment costs also relatively rare
Consumers	When CGE model used, quantify changes in prices and effects on household consumption; sometimes also regional effects	Many CGE models have representative consumer; predicted price effects sometimes combined with consumer expenditure survey data to estimate effects by income
Economic growth, technological efficiency	When CGE model used, changes in GDP growth reported; LR effects on technological efficiency not typically quantified	CGE models evaluate changes in GDP in addition to economic welfare
Governments and non-profits	When there are new monitoring and enforcement requirements, accounting analysis often used to quantify required hours and cost burdens. See row 1 regarding price and quantity sectoral effects.	CGE models estimate implications of behavioral changes for some tax revenues (e.g., income or labor taxes) but only represent the government sector generically and do not separately track non-profits.

Another key question when determining the type of modeling tool to use for analysis of benefits, costs, or economic impacts is whether the compliance costs incurred by regulated firms are of sufficient magnitude that we expect significant behavioral changes that result in macroeconomic feedbacks. Data from the Pollution Abatement and Cost Expenditure (PACE) survey indicate that expenditures to reduce emissions are often a relatively small fraction of total manufacturing revenues compared to other non-abatement expenses. Likewise, while environmental control expenditures “are large in absolute terms, [they] still account for a fairly small fraction of gross national product” (Portney, 1981). The Office of Management and Budget (OMB, 1995) notes that macroeconomic effects tend to show up in national level models “only if the economic impact of the regulation reaches 0.25 percent to 0.5 percent of Gross Domestic Product ... A regulation with a smaller aggregate effect is highly unlikely to have any measurable impact in macro-economic terms unless it is highly focused on a particular geographic region or economic sector.”<sup>5</sup> In 2014, this amounts to about \$43 billion - \$87 billion.<sup>6</sup>

OMB’s suggested threshold provides some context for the relatively rare use of CGE models by EPA for analyzing the impacts of a specific air regulation. In combination, the 24 major air regulations promulgated by EPA between fiscal years 2003 and 2013 had total annual costs of \$41 billion to \$49 billion (in 2014 dollars) (OMB, 2015). Using OMB’s threshold as a guide, an economy-wide approach could potentially provide useful insights with regard to the effects of EPA’s air regulations in aggregate (and in fact, U.S. EPA (2011c) uses a CGE model to evaluate the benefits, costs, and sectoral impacts of the Clean Air Act Amendments). The most expensive individual air regulation during this time period, the Utility MACT, had annualized costs of about \$11 billion (2014\$), well below the OMB threshold.<sup>7,8</sup>

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<sup>5</sup> The Congressional Budget Office (CBO) and Joint Committee on Taxation (JCT) are required to “examine the budgetary effects of changes in macroeconomic variables resulting from legislation that has a gross budgetary effect of 0.25 percent of GDP – excluding the macro-economic feedback – in any year over the next ten years.” To evaluate SR effects, the CBO uses a demand multiplier (i.e., how much a change in output directly contributes to demand). To evaluate LR effects, it uses Solow growth and overlapping generations lifecycle growth macro models, which differ in what they assume about the role of expectations about future policy. For more information, see <https://www.cbo.gov/publication/50730>.

<sup>6</sup> According to the U.S. Department of Commerce’s Bureau of Economic Analysis, U.S. GDP was \$17.4 trillion in 2014 (Annual GDP available at: [www.bea.gov](http://www.bea.gov)).

<sup>7</sup> An open question is how explicit consideration of monetized benefits in an economy-wide framework could affect potential macroeconomic feedbacks (see the benefits white paper). The Utility MACT regulation had monetized benefits of \$37 billion - \$103 billion (in 2014 dollars), but the potential magnitude of its effect on GDP is unclear. Recall that EPA (2011c) estimated net welfare improvements when compliance costs and health benefits were both included in the CGE model. Net GDP effects were smaller once health improvements were included.

<sup>8</sup> An OSHA regulation with about \$1 billion in first-year costs was analyzed using an I-O macro-econometric model (i.e., the Inforum LIFT model). Werling (2011) finds that, “Across ten years, the cumulative employment impact is a gain of 8,625 job-years. The positive net employment impact is due mostly to additional jobs created in the construction industry. Cumulative employment in other sectors declines slightly.... in no individual sector does the difference for output, prices, or employment exceed 0.1 percent of the baseline level in absolute terms ... In other words, ... the silica rule leaves a negligible footprint on the economy because, ... the compliance costs are very small in proportion to gross output and costs, even for the most affected sectors” (p. 6).

### 3. Quantitative evaluation of economic impacts by EPA

This section discusses examples of how EPA has evaluated the categories of economic impacts highlighted in the charge (i.e., short and long run energy prices, sectoral impacts, transition costs in capital or labor markets, equilibrium impacts on labor productivity, supply or demand, and effects on households on the basis of income) for recent air regulations.<sup>9</sup> For expository purposes, we organize EPA air regulations into four distinct categories, which are described in detail in the social cost white paper. As previously mentioned, CGE models have only been used in a small subset of cases, all of which can be categorized as regional or state-implemented emission targets. This section also describes challenges associated with estimating economic impacts for other rule categories, though EPA has not used CGE models in this context to date. In addition, we briefly describe the EPA's use of CGE models to evaluate the economic impacts of proposed climate legislation.

While CGE models are not often used by EPA to evaluate economic impacts, it is important to note that these impacts do not remain unquantified. For instance, in the case of energy prices, EPA typically relies on engineering or partial equilibrium models when a CGE model is not utilized. For economically significant rules that regulate energy-related sectors, a detailed electricity sector dispatch model, the Integrated Planning Model (IPM), is frequently used (i.e., a multiregional, dynamic deterministic linear programming model of the U.S. electric power sector). In particular, EPA has used IPM to estimate projected changes in wholesale and retail electricity prices at the regional and national levels, wholesale, retail, and delivered prices for natural gas and oil, mine mouth and delivered prices of coal, and changes in projected capacity for different fuel types (e.g. coal fired generation), among others.

Likewise, employment impacts in the regulated, pollution abatement, and related sectors have been characterized for economically significant air quality regulations using either a qualitative or bottom-up approach that relies on information from the BCA to estimate labor requirements for implementing particular technologies or practices. For example, for many recent analyses of air regulations, detailed compliance projections for the electricity sector (from IPM) have been combined with information on specific labor requirements for manufacturing, installing, and operating pollution control equipment to estimate direct employment impacts. Indirect employment impacts in related sectors such as coal and natural gas production have been based on combining projected changes in utilization and fuel use projected by IPM with detailed labor productivity information on coal and natural gas production. Employment impact estimates are often separated into short-term impacts associated with construction, manufacturing, and installation of pollution control equipment or processes, and longer-term impacts from ongoing operation and maintenance.

In addition to noting the difficulty of disentangling the effects of a specific regulation from many other factors that affect employment, EPA includes a statement in its analyses that even a large-scale regulation is unlikely to have a noticeable impact on aggregate net employment when the U.S. economy

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<sup>9</sup> The potential role of CGE models for evaluating competitiveness effects are discussed in a separate memo.

is at full employment. Instead, labor would shift from one productive use to another, and net national employment effects from regulation would be small and transitory.<sup>10</sup> When the U.S. economy is at less than full employment, EPA observes that economic theory does not provide a clear prediction of the direction or magnitude of the net impact on employment from regulation; it could cause either a short-run net increase or short-run net decrease.

### 3.1 Regional or State-Implemented Emission Targets

We found five instances in which EPA has used CGE models to analyze the economic impacts of recent air regulations. They are the final Clean Air Interstate Rule (CAIR) (U.S. EPA, 2005a), final Clean Air Visibility Rule or Best Achievable Retrofit Technology (BART) Determinations under Regional Haze Regulations (U.S. EPA, 2005b), 2006 final Particulate Matter National Ambient Air Quality Standards (NAAQS) (U.S. EPA, 2006), 2008 final Ozone NAAQS (U.S. EPA, 2008), and proposed 2010 Cross-State Air Pollution Rule (CSAPR) (U.S. EPA, 2010b).

All of these regulations are economically significant.<sup>11</sup> Three of these regulations directly regulate emissions from the electricity sector and certain industrial boilers (CAIR, BART and CSAPR), while emission reductions from the two NAAQS standards are assumed to come from a wide variety of sectors (e.g., transportation, electricity, and industrial). Total annual private compliance costs for regulated point sources ranged from \$750 million (for the 2006 Particulate Matter NAAQS) to \$3.8 billion (for CAIR), while partial equilibrium estimates of social costs ranged from \$1.4 billion (for BART) to \$7.7 billion (for the 2008 Ozone NAAQS) in 2001 dollars. For each analysis, a CGE model was used to estimate the aggregate macroeconomic effects of the regulation on the U.S. economy measured in terms of effects on GDP, consumption and, in one instance, equivalent variation.

In four of the five cases where EPA used CGE models to examine the economic impacts of an air regulation, it used the detailed electricity dispatch Integrated Planning Model (IPM) to estimate effects on energy prices, and then used these prices as inputs into the CGE model. A main reason for this approach is that sulfur dioxide, nitrous oxide, and mercury emissions are not necessarily proportional to fuel use due to the ability to lower emissions via actions such as fuel switching and/or installing retrofit equipment. As noted in the BART regulatory analysis, “The boiler- and firm-specific natures 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 possibly the construction of new generating units) can affect electricity prices, manufacturing costs, and fuel use, a detailed characterization of the electricity and industrial markets is preferable when estimating implications of policies like the BART guidance”(U.S. EPA, 2005b).

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<sup>10</sup> Full employment is a conceptual target for the economy where everyone who wants to work and is available to do so at prevailing wages is actively employed. The unemployment rate at full employment is not zero.

<sup>11</sup> A rule is economically significant if it is expected to have an effect on monetized benefits or costs of \$100 million or more in any single year or would adversely affect in a material way the economy, a sector of the economy, or the environment.

CGE modeling was used to identify potential effects on other sectors that derived from interactions between the directly regulated sector(s) and the rest of the economy via changes in energy prices. The total number of sectors evaluated in the CGE model varied across regulatory analyses (i.e., 16 sectors in the EMPAX model; 35 sectors in the IGEM model). In each case, results were discussed in terms of impacts on energy sectors, energy-intensive manufacturing sectors, and non-energy sectors. In general, the CGE model results demonstrated relatively small effects of these regulations on individual sectors, reported in terms of percent changes in sectoral output and, occasionally, revenues. For example, for CAIR, output in sectors apart from electricity and coal was expected to change – either in a positive or negative direction – by about 0.05 percent, on average, with the largest expected decline in output reaching 0.2 percent nationwide (U.S. EPA, 2005a). Both the Particulate Matter and Ozone NAAQS analyses find similarly small effects on average and for energy-intensive sectors. The analysis for the proposed CSAPR rule reports output changes in each energy-intensive sector of less than 0.1% and in non-energy sectors of 0.01% (U.S. EPA, 2010b). In each of these cases, some regional shifts in energy production were expected to occur because of the uneven geographic distribution of regulated entities (e.g., electricity generation in the West was relatively unaffected by CAIR). The analyses also evaluated regional differences in energy-intensive and non-energy sector effects due to differences in production methods and energy prices, but these effects were also relatively small.

In two cases, the CAIR and BART rules, a CGE model was also used to examine impacts on households in terms of consumption, changes in the real wage, and/or the number of hours worked. On average, consumer price changes were estimated to be small (e.g., between 0.02% and 0.04% for CAIR due to direct (i.e., electricity) and indirect (i.e., goods that use electricity in production) effects (U.S. EPA, 2005a)). Evaluation of changes in the labor market were limited to long run equilibrium effects due to the nature of the model utilized (i.e., a full employment CGE model with instantaneous adjustment to a new equilibrium after the policy shock). In this case, it is possible for a representative household to respond to changes in the real wage rate by voluntarily changing the number of hours worked (instead consuming relatively more leisure). For example, in response to CAIR, the real wage is estimated to decline slightly and representative households are predicted to work slightly fewer hours overall. In this case, the substitution effect (of leisure for labor) is estimated to dominate the income effect (consumers work more to offset additional costs of more expensive goods) (U.S. EPA, 2005a). Involuntary unemployment is not modeled.

As previously mentioned, all five of the recent air regulations for which EPA used a CGE model to evaluate economic impacts can be characterized as regional or state-implemented emission targets.<sup>12</sup> Many of the challenges inherent in estimating the social cost of these types of regulations also make it challenging to accurately characterize economic impacts. For instance, implementation of a NAAQS

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<sup>12</sup> Regional- or state-implemented emission targets often cover multiple sectors, are implemented over an extended period of time (5-10 years), are typically (though not always) large in terms of monetized benefits and compliance costs, and may be national or regionally focused. These types of regulations often allow for flexibility at both the firm and jurisdictional level in terms of what controls or approaches are used to achieve emission levels or air quality standards. For example, NAAQS are implemented by the states and transport regulations (i.e., when pollutants travel long distances and potentially cross state borders) and may include emissions trading.

regulation can take a decade. Once the regulation is promulgated, states design control strategies, submit them to EPA for approval, and then implement them. The federal standards do not specify which emission sources must make emissions reductions and which technologies must be used to meet the standards. Instead, states and counties choose a combination of emission reduction measures across a wide variety of sectors to achieve the standard (e.g., they may opt for a market-based trading approach, specify abatement technology or fuel switching strategies for new sources, invest in public transportation or other lower emission commuting options, and/or conduct vehicle retrofits for existing mobile sources). Thus, there is significant uncertainty regarding state-implementation when attempting to evaluate how economic impacts vary by sector or affect energy prices or labor markets. Given this uncertainty in how a NAAQS will be achieved, EPA estimates the least-cost approach available for meeting the standard using identified control strategies. However, it considers this only illustrative as abatement strategies will likely vary by state or region to reflect local composition of emission sources, meteorological conditions, and preferences for different compliance approaches. Even when engineering and PE models account for regional differences, existing CGE models often do not have enough spatial resolution or may not reflect the same regional configuration as the detailed models.

In addition, once all known emissions control technologies have been identified and applied to attain the standard, some areas of the country may still be modeled as out of compliance with the NAAQS. That is, the inventory of all known incremental controls may be insufficient to bring these areas into attainment with the tighter standard. In these cases, to estimate the benefits, costs, and impacts of the NAAQS, EPA has extrapolated compliance costs for a set of unidentified controls to simulate bringing these areas into compliance. Representing extrapolated costs in a CGE context is particularly challenging because of a lack of specificity about the types of inputs required and inability to apportion them to specific industries. This leaves the analyst with a choice between omitting these costs from the CGE estimation, which renders an estimate of social cost incomplete, or making additional assumptions about how and in what industries they will be implemented, further exacerbating estimation uncertainty. EPA opted to exclude extrapolated costs from its CGE modeling exercises when estimating the impacts of the Ozone and Particulate Matter NAAQS but clearly stated the limitation placed on the analysis in each instance from doing so.

### 3.2 Other Types of Air Regulations

To date, EPA has not relied on CGE models to evaluate the economic impacts of other types of air regulations such as single sector emission rate limits, multi-sector boiler or engine-level emission limits, or federal product standards, though they have at times been used to estimate social cost. Instead, the Agency has tended to rely on sector-specific models or approaches when these economic impacts are evaluated in the context of a particular rulemaking. Below we briefly revisit some of the key challenges in accurately modeling these types of regulations in a CGE framework - taken from the social cost white paper - that may be particularly relevant when estimating economic impacts on specific sectors or inputs to production (e.g., labor, capital, energy).

### 3.2.1 Single Sector Emission Rate Limits

In the case of single sector emission rate limits, EPA typically has relatively good information on which entities will be affected, the technologies available for compliance, and engineering-based cost estimates associated with these technologies.<sup>13</sup> We revisit the example of the 2011 Mercury and Air Toxics Standards (MATS) to highlight key challenges that may limit the added value of a CGE approach over a detailed partial equilibrium sector model when estimating economic impacts (See U.S. EPA, 2011a for more detail).

For MATS, methods and costs of compliance are expected to vary significantly by type of generating unit. In particular, the compliance strategy is expected to depend on factors such as (but not limited to) facility age, the technology used by the facility, forecasted prices of different types of fuel and the different grades of fuel available, the costs of retrofitting technology for a specific facility, the costs of building new facilities or new capacity at other facilities, and shut-down costs. Geographical location is also important due to difference in fuel availability, degree of competitiveness in markets for electricity, and electricity transmission constraints across regions. There are also important and complex relationships in the control of air pollutants. For example, one coal type may contain more of one pollutant and less of another relative to another coal type.

While CGE models of the U.S. economy vary greatly in sector detail, even those that are relatively disaggregated often represent electric utilities with just a few categories of technology (see Table 9 in section 5.4). These models do not allow an analyst to capture differences in compliance options associated with multiple emission limits differentiated by vintage, fuel source, and technology, the complementarities and tradeoffs in control of these pollutants, or the flexibility afforded regulated entities in methods of compliance. Nor do they allow for separating out electric generating units not affected by the regulation. In contrast, a detailed partial equilibrium sector model may be able to capture many of the methods individual sources use to comply with MATS as well as consequent effects on electricity and natural gas prices.

For MATS, EPA used the electricity sector dispatch model, IPM, to capture these nuances and describe economic impacts on a more disaggregated level than would be feasible using a CGE model. For instance, EPA examined the impacts of MATS on national and regional wholesale and retail electricity and natural gas prices, as well as on coal production by region. Based on detailed information from IPM on the number and scale of pollution controls required and their labor intensities, EPA then estimated employment impacts in the directly regulated sector, including short-term impacts associated with pollution control equipment installed prior to the MATS compliance date.

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<sup>13</sup> This category of regulations can be characterized as rate-based emission limits applied to an individual production unit or facility within a single sector or sub-sector. Regulated sectors in this category often provide key inputs to other upstream economic sectors. The regulations are typically national in scope, though a sector may be geographically concentrated in a particular region of the country. They are performance-based standards that do not require specific control measures. The regulations vary widely with regard to magnitude of costs and benefits.

### *3.2.2 Multi-Sector Boiler or Engine-Level Emission Limits*

The regulated universe for multi-sector boiler or engine-level emission limits is often highly disparate and difficult to identify.<sup>14</sup> While there is typically good information on the compliance technology options available and the costs associated with implementing them, the distribution of these costs across sectors and regions is uncertain. We revisit the example of the National Emission Standards for Hazardous Air Pollutants for Industrial, Commercial, and Institutional Boilers and Process Heaters (i.e., Boiler MACT) to illustrate how lack of information on which facilities or sectors are affected can complicate a detailed assessment of economic impacts (U.S. EPA, 2011b).

With respect to the Boiler MACT, CGE models typically do not provide enough detail to allow for an accurate depiction of how technology choice varies by boiler type. In many cases this variation occurs at a sub-sector level and across existing and new boilers, given different standards. It is also the case that some sectors as defined in a CGE model include a mix of facilities that are and are not subject to the rule. For instance, health services includes hospitals, which are covered by the regulation, but also includes nursing care facilities, which are not. Linking a CGE model to detailed partial equilibrium sector models to capture heterogeneity in compliance while accounting for general equilibrium effects may also be relatively complicated due to the wide range of sectors affected. In the case of Boiler MACT, EPA used a short run, static partial equilibrium model representing multiple markets to report expected changes in prices and quantities.

### *3.3.3 Federal Product Standards*

The economic impacts of a product standard may be difficult to estimate because regulatory requirements affect the quality and availability of certain consumer products.<sup>15</sup> In some cases, attributes valued by the consumer (e.g, durability, performance, reliability) could be negatively or positively affected. We revisit the example of the Volatile Organic Compounds (VOC) Emissions Standard for Consumer Products to illustrate some of the challenges in identifying impacts in specific sectors from these types of regulations (U.S. EPA, 1996).

The VOC Emissions Standard mandates a specific limit for 24 consumer products, which requires a change in the way they are manufactured in order to reduce VOC content. Many of the consumer products affected by the regulation are narrowly defined (e.g., air fresheners, hair mousse, floor

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<sup>14</sup> These regulations are usually rate-based emission limits applied to specific types of technologies commonly used across disparate sectors. They are typically national in scope and have large aggregate compliance costs due to the sheer number of units subject to the limits. Compliance is typically required five years or less from promulgation.

<sup>15</sup> This category includes federal standards that regulate features of manufactured products used by households and other sectors (e.g., in-use emission rate requirements for vehicles and product content requirements). Standards in this category focus on certain product qualities and/or availability instead of on emissions that stem from the manufacturing process. While there are many products potentially affected, regulations typically apply to the product manufacturer.

polishes and waxes, underarm deodorant) and likely only represent a small portion of a more aggregate sector in a CGE model. As such, substitution away from a regulated product to unregulated alternatives within the same sector would be entirely missed by a CGE model. In addition to capturing changes in the price of these products it may also be important to reflect changes in product quality. However, sector outputs are usually assumed to be homogenous in a CGE model.

Thus, in this case EPA relied on a partial equilibrium approach. It first evaluated the decision of a firm to reformulate or withdraw a product from the market under different profit margin assumptions in response to the regulation. It then used this information to analyze changes in price and quantity in a particular sector in response to a reduction in the number of products available and an increase in the cost of products that remain on the market. Demand and supply elasticities were either drawn from the literature or directly estimated. Potential cross-sector effects were not taken into account.

### 3.3 Use of CGE Models for Legislative Analyses

CGE models have been more regularly employed by EPA to analyze the effects of proposed climate legislation (in total about ten times). A rough comparison with the air regulations described above indicates that the effects of proposed climate legislation on regulated entities was expected to be noticeably larger (i.e., MATS was estimated to have annual aggregate compliance costs of approximately \$8.2 billion in 2001 dollars, while EPA estimated that the American Power Act (APA) had annual total abatement costs in 2020 of \$25 billion to \$28 billion in 2001 dollars). While conducted in a different setting (e.g., with different expectations regarding scope, budget, and timeline) than an air regulation, we briefly highlight how CGE modeling has been leveraged to evaluate climate legislation for the economic impact categories mentioned in the charge. As EPA often used the same CGE models (i.e., ADAGE and IGEM) and general analytic approach to analyze various legislative climate proposals, we limit the discussion to the most recent example, the APA (U.S. EPA 2010c).<sup>16</sup>

#### *3.3.1 Energy Price and Sectoral Impacts*

The analysis of the APA reported changes in electricity and primary energy prices from the ADAGE model. Table 3 shows the projected effect of the legislation on energy prices, both inclusive and exclusive of CO<sub>2</sub> prices, under three scenarios in 2020. Under the APA core policy scenario, the price of coal, inclusive of the carbon price, rose by more than other fuels because it had the highest carbon intensity. Coal also had lower costs of extraction per unit of energy and lower processing and refining expenses, which helps to explain the smaller fraction price increase (5% to 17%) for natural gas and petroleum. The price effects exclusive of the carbon price showed a slightly depressed price for coal and increased price for natural gas reflecting the changes in demand for those resources.

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<sup>16</sup> The APA, introduced into the U.S. Senate in 2010, proposed a declining cap for U.S. greenhouse gas emissions beginning in 2013. Reduction targets were 17% below 2005 levels in 2020 and rose to an 83% reduction by 2050.

**Table 3. Energy price index (Reference =1) in 2020 for the American Power Act (EPA 2010c)**

	APA Core Policy (Scenario 2)	APA Restricted Tech (Scenario 7)	APA with IPM (Scenario 8)
Price index over Reference, inclusive of CO <sub>2</sub> price			
Electricity	1.21	1.47	1.21
Coal	2.25	4.06	2.49
Natural gas	1.17	1.42	1.19
Refined petroleum	1.05	1.16	1.07
Price index over Reference, exclusive of CO <sub>2</sub> price			
Coal	0.99	0.96	na
Natural gas	1.01	1.01	na
Refined petroleum	1.00	1.00	na
<i>Allowance Price (\$/tCO<sub>2</sub>)</i>	23.9	58.6	23.9

Under a restricted technology scenario limiting the expansion of nuclear power and biomass and delaying the availability of carbon capture and sequestration, the price increases inclusive of the carbon price were significantly higher due to the higher allowance price needed to meet emission targets. To utilize the strengths of the electricity sector model, IPM, a third scenario introduced the CO<sub>2</sub> allowance price projections and change in electricity demand from ADAGE into IPM. This was a one-way linkage; the results from the electricity sector model did not feedback into the CGE model. The changes in energy prices were very similar between the core scenario and the scenario using IPM. (See the social cost white paper for a discussion of linking a CGE model with a detailed sector model.)

In addition to evaluating effects on energy prices, EPA also examined the impact of the APA on quantities of different fuels used to generate electricity and on near-term coal production. Because CGE models do not include detailed representation of specific technologies, long run CO<sub>2</sub> allowance prices and changes in electricity demand predicted by the CGE model were used as inputs into IPM, which then produced new generation and retirement estimates by fuel type (e.g., coal with and without carbon capture and storage, nuclear, renewables, natural gas). Once again, this was a one-way linkage.

EPA also analyzed the effects of proposed climate legislation on household energy expenditures and total household consumption (i.e., higher energy prices, price changes for other goods and services, impacts on wages and returns to capital, and the value of auction revenues returned lump sum to households but no changes in leisure). In 2020, electricity prices were identical to the reference case. In 2030 they increased by 27% over reference; in 2050 they increased by 52%. The net present value of consumption loss per household was relatively modest (e.g., \$55 to \$190 in 2030), likely in part because of provisions designed to reduce the effect of the policy on electricity prices.

### *3.3.2 Capital and Labor Markets*

The CGE models used in the analysis of APA (i.e., ADAGE and IGEM) are long-run, full employment models. Both models represent the choice between labor and leisure, and thus long-run, voluntary changes in labor supply are modeled (though labor supply elasticity assumptions vary across models). To the extent that the APA changed the relative returns to labor, households could voluntarily opt to work less (or more), while increasing (or decreasing) the amount of leisure they consumed. The analysis did not explicitly report how wages and labor-leisure trade-offs were affected by the policy, however.

The two CGE models differ in their treatment of capital markets. While ADAGE includes capital adjustment costs, capital in IGEM moves across sectors costlessly. That said, EPA exogenously constrained the pace at which various electricity generating technologies could enter the market to better reflect how quickly they could be built and brought online. These limits are imposed on new renewable, nuclear, and coal units with carbon capture and sequestration.

### *3.3.3 Income Distribution*

EPA adapted methodology from Burtraw et al. (2009) to evaluate the distributional implications of the APA across ten income classes (meant to reflect demographic differences across the U.S. population based on recent Consumer Expenditure Survey data). Because demographic characteristics and consumption patterns can evolve over time but the incidence model is a static partial equilibrium framework, EPA only analyzed the distributional implications of the proposed legislation in a near-term year (i.e., 2016). The incidence model did not take the price changes of goods and total consumption changes directly from ADAGE with the exception of electricity price, and assumed full pass through of allowance prices to consumers. Abatement costs in each sector in the incidence model were calibrated to total abatement costs from ADAGE. Price changes for energy-intensive goods consumed by households and producers were estimated based on the carbon content of fuel and the allowance price, and indirect price increases for other final goods were estimated based on the share of energy inputs used to produce them. These were then combined with information on the relative consumption of different goods in the incidence model to estimate changes in consumer surplus by decile. EPA found that welfare increases for the bottom two income deciles and the top income decile by more than the increased cost of goods affected by the policy. The majority of the APA's costs were expected to be borne by households in the fourth to ninth income deciles.

## **4. Economy-wide approaches to analyzing economic impacts of EPA air regulations by outside organizations**

Economy-wide analyses of specific air regulations in the academic literature are relatively rare. Several studies are discussed in Section 5 along with a broader discussion of modeling techniques and issues from the academic literature that could inform future improvements to EPA's analyses of air regulations using an economy-wide framework. However, a number of studies sponsored or conducted by outside

organizations are available in the unpublished, grey literature. This section provides a brief overview of the types of models used by outside organizations to conduct economy-wide analyses of the economic impacts of specific EPA air regulations. Finally, this section describes the metrics used by the subset of studies that characterize employment impacts for the air regulations analyzed.

A search of the grey literature yielded 22 studies conducted or sponsored by outside organizations between 2008 and 2015 that use an economy-wide approach to examine the economic impacts of one or more EPA air regulations (Table 4). To our knowledge, none of these have been formally peer reviewed. Almost two thirds of the 22 studies focused on regulations in the electric utility sector (e.g., the Clean Power Plan, MATS, CSAPR). In comparison, five studies examined regulations in the transportation sector. Four economy-wide studies focused on a regulation that affects many sectors at once such as the Boiler MACT or Ozone NAAQS. While it is possible that other studies of EPA regulations exist, the 22 studies summarized in this section should provide a broad enough cross-section to be instructive regarding the types of analyses typically conducted.

Note that seven of the studies— some of which overlap with the categories discussed above - evaluated the combined effects of a collection of proposed and final regulations on a sector over a given time period. In these studies, the selected regulations sometimes go beyond air rules. For instance, the Electric Power Research Institute (EPRI) examined the implications of the combined effects of the MATS final rule and two proposed rules, CCR and 316(b), rules promulgated under RCRA and CWA, respectively, on energy prices (EPRI, 2012). We include these studies in our discussion, but emphasize that for purposes of satisfying E.O. 12866, Circular A4, and EPA's Economic Guidelines, an already promulgated is in the baseline when evaluating the incremental effects of a single proposed regulation. As one might anticipate, the majority of the studies focused on proposed regulations since they then have the potential to influence stakeholders and/or EPA in crafting the final regulation. In a few of cases, the study by an outside organization preceded EPA's proposed rule and therefore the scenarios analyzed are hypothetical (i.e., based on a best guess of what EPA might do).

A total of 15 studies estimated the effects of a regulation or set of regulations on employment, with 9 of these studies focusing exclusively on employment impacts. Thirteen studies examined the impacts of regulation on energy prices and/or individual industry sectors. We found no studies by outside organizations that examined the implications of a specific air regulation on consumers by income class, though several reported effects on overall consumption or GDP. (Recall, we discussed these measures as proxies for changes in economic welfare in the social cost white paper. They are not discussed here.)

The specific economy-wide modeling approach utilized by outside organizations for evaluating the effects of EPA air regulations also varied. Eleven of the 22 studies relied on U.S. CGE models (i.e., NewERA or U.S. REGEN). The studies that relied on CGE models were used to examine changes in energy prices, sectoral impacts, and employment. Seven studies included in Table 4 relied on an input-output (I-O) model as their basic analytic approach. This approach was used almost exclusively to examine the impacts of specific air regulations on employment. Two of the studies utilized an I-O macro-econometric model (i.e., the Inforum LIFT model). The remaining studies combined different partial equilibrium or engineering models in an attempt to approximate economy-wide effects.

**Table 4. Summary of Outside Organization Studies of EPA Air Regulations Using Economy-Wide Modeling Approaches**

<b>AUTHOR<sup>17</sup></b>	<b>EPA REGULATION</b>	<b>INPUT ASSUMPTIONS SIMILAR TO EPA?</b>	<b>POLICY SCENARIOS SIMILAR TO EPA?</b>	<b>IMPACT CATEGORIES STUDIED</b>	<b>MODEL TYPE (SPECIFIC MODEL)</b>
<b>NERA (2016)</b>	CPP Model Rule (P)	No	Yes, + 5 scenarios	Energy prices	CGE (NewERA)
<b>NERA (2015A)</b>	CPP (F)	Yes	Yes + 1 scenario	Energy prices	CGE (NewERA)
<b>NERA (2015B)</b>	RFS2 adv. biofuel vols. (P)	No	No	Energy prices	CGE (NewERA) + transportation fuel model
<b>BIVENS (2015)</b>	CPP (P)	Yes	Yes	Employment	IO + VAR and state-panel regressions
<b>IEC AND IERF (2015)</b>	CPP (P)	Yes	Yes	Employment	IO-macro-econometric (Inforum LIFT)
<b>NERA (2015C)</b>	Ozone NAAQS (P)	No	Yes	Sector, employment, and energy price impacts	CGE (NewERA)
<b>NERA (2014A)</b>	CPP (P)	No	Yes, + 1 scenario but - another	Energy prices	CGE (NewERA)
<b>NERA (2014B)</b>	Ozone NAAQS (H)	No	No	Sector, employment, and energy price impacts	CGE NewERA)
<b>EPRI (2013)</b>	GHG NSPS (P)	No	No	Sector impacts	CGE (US-REGEN)
<b>SMITH AND GANS (2013)</b>	CSPAR (F) Boiler MACT (F) Ozone NAAQS (P)	No	Yes Yes No	Employment	CGE (NewERA)
<b>EPRI (2012)</b>	MATS (F) CCR (P) 316(b) (P)	No	Yes Yes, - 1 scenario Yes	Energy prices	CGE (US-REGEN)
<b>BUSCH, ET AL. (2012)</b>	Light Duty GHG stds, MY 2017-2025 (P)	Yes	Yes, + 2 scenarios	Employment	IO (DEEPER)
<b>NERA (2012)</b>	MATS (F) Regional Haze (H)	No No	Yes No	Energy prices, and employment	CGE (NewERA)

<sup>17</sup> The organizations that sponsored a particular study are listed in the references.

<b>AUTHOR<sup>17</sup></b>	<b>EPA REGULATION</b>	<b>INPUT ASSUMPTIONS SIMILAR TO EPA?</b>	<b>POLICY SCENARIOS SIMILAR TO EPA?</b>	<b>IMPACT CATEGORIES STUDIED</b>	<b>MODEL TYPE (SPECIFIC MODEL)</b>
	Ozone NAAQS (H)	Yes +	No		
	PM NAAQS (H)	No	No		
	SO2 NAAQS (F)	Yes	Yes		
	316(b) (P)	Yes	Yes		
	CCR (P)	Yes	Yes, - 1 scenario		
<b>SMITH, ET AL. (2012)</b>	MATS (F)	Yes	Yes, + 1 scenario	Employment	CGE (NewERA)
<b>NERA (2011A)</b>	CSPAR (F)	No	Yes	Energy prices, and employment	REMI PI+, NEMS, Coal Unit Retirement Model
	MATS (P)	No	Yes		
	316(b) (P)	Yes	Yes		
	CCR (P)	Yes	Yes, - 1 scenario		
<b>CICCHETTI (2011)</b>	MATS (P)	Yes	Yes	Employment	IO (RIMS II)
<b>NERA (2011B)</b>	MATS and Transport (P)	No	No	Energy prices, and employment	NERA Retirement Model, NEMS, REMI
<b>U. MASS, PERI, ET AL. (2011)</b>	MATS and Transport (H/P)	No	No	Employment	IO (IMPLAN)
<b>GOLDBERG (2011)</b>	MHD Vehicle GHG Stds (P)	No	Yes	Employment	IO (IMPLAN)
<b>GLOBAL INSIGHT IHS (2010)</b>	Boiler MACT (P)	No	Yes, + 2 scenarios	Employment, and sector impacts	IO (IMPLAN)
<b>BAUM AND LURIA (2010)</b>	CAFE (H)	No	No	Employment	IO (using REMI multipliers)
<b>MEADE (2009)</b>	CAFE and RFS2 (F)	No	No	Sector impacts	IO-macro-econometric (Inforum LIFT)

Notes: H = hypothetical regulation, P= proposed regulation, F= final regulation

CPP = Clean Power Plan; NAAQS= National Ambient Air Quality Standards; RFS2 = Renewable Fuels Standard; GHG NSPS = Greenhouse Gas New Source Performance Standard; CCR = Coal Combustion Residual; MATS = Mercury Air Toxics Standards; CAFE = Corporate Average Fuel Economy; MHD = Medium-Heavy Duty; MACT = Maximum Achievable Control Technology; CSPAR = Cross-State Air Pollution Rule

## 4.1 Model Choice

It is relatively rare to find a formal comparison of how estimated impacts from a policy change are affected by model choice in the academic literature. A prominent example that is discussed in the “Economy-Wide Modeling: Uncertainty, Verification, and Validation” white paper is Stanford’s Energy Modeling Forum (EMF). Hoffman et al. (1996) is also potentially instructive. They approximated the effect of model choice on labor market predictions for a change in defense spending in California by altering assumptions about what is fixed in a state-level CGE model. For instance, they approximated an extended input-output approach by fixing wages and prices. In this case, all responses to the policy occurred through changes in quantities. They also explored fixing aggregate factor supplies (e.g., labor supply) while wages and prices responded endogenously. Hoffman et al. (1996) predicted little effect on employment when wages were treated endogenously but a 9-12 percent decline in state employment when prices and wages were not allowed to respond. Since model choice may have an effect on the estimated economic impacts of a policy, we briefly summarize the three main types of economy-wide models used by outside organizations to explore labor, energy, and sectoral impacts: CGE models, I-O models, and I-O macro-econometric models, respectively.

### 4.1.1 CGE Modeling

Recall that CGE models assume that “for some discrete period of time, an economy can be characterized by a set of equilibrium conditions in which supply equals demand in all markets. When the imposition of a regulation alters conditions in one market, [the CGE] model will determine a new set of prices for all markets that will return the economy to equilibrium. These prices in turn determine the outputs and consumption of goods and services in the new equilibrium. In addition, the model will determine a new set of prices and demands for the factors of production,... the returns to which compose the income of businesses and households” (U.S. EPA, 2010a). As previously discussed in the social cost white paper, CGE models have been used to examine the welfare implications of environmental regulation. We also are interested in understanding whether a CGE model adds value with regard to the economic impacts of interest to EPA and outside organizations in a comprehensive and analytically consistent way (acknowledging that this ignores the role that benefits should play in determining such impacts).<sup>18</sup>

With respect to energy prices, studies from Table 4 that relied on the NewERA model typically reported the estimated national and regionally differentiated average delivered price of electricity, and the average Henry Hub spot price of natural gas (in levels and as a percentage change from reference).

Similar to the CGE models EPA has used to evaluate the impacts of its regulations, the U.S. REGEN and NewERA models assume that markets simultaneously clear in every period and all economic resources

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<sup>18</sup> NewERA and U.S. REGEN are iteratively linked to detailed electricity sector models. This approach nests a technology rich representation of the energy system to reflect the range of fuels, capacity, and other characteristics of generating units as well as installation, operation, and maintenance costs and constraints based on load, transmission, and regulations within a consistent framework that propagates price changes through the economy and captures interactions between producers and consumers. NewERA also has been linked to a detailed transportation sector model (NERA, 2015b).

are fully employed. In the labor market, this means that anyone that wants a job at the prevailing wage can find one. Changes in labor supply that result from a policy shock are “voluntary” (i.e., they do not model involuntary unemployment). Workers modify their labor-leisure choices in response to a change in the wage rate. They also assume away potential short-term adjustment costs that are often of interest to decision-makers, stakeholders, and the public (U.S. EPA, 2010; COC and NERA, 2013). Nevertheless, four studies listed in Table 4 – all of which relied on the NewERA CGE model - reported the effects of regulation on employment in the long run. See section 4.3 for a more detailed discussion of the metrics used to present this information.

#### *4.1.2 Input-Output Modeling*

Input-output models are highly disaggregated empirical descriptions of the interrelated flows of good and factors of production. I-O models are generally static and assume a fixed, strictly proportional relationship between input coefficients and outputs via multipliers (e.g., EPA, 2010a). While an I-O model is “economy-wide” with regard to sectoral and regional coverage, it is sometimes described as a partial equilibrium approach because it does not allow producers and consumers to respond to new information that would normally be transmitted via price changes, does not include resource constraints, and does not account for the fact that demand for an affected good depends on more than its own price (COC and NERA, 2013; OECD 2004, Dwyer, et al., 2006, Adkins, et al., 2012).

EPA’s Economic Guidelines note that the assumption that output changes translate directly to proportional changes in labor inputs is faulty and therefore should not be used – even in the short run - because it ignores the potential for factor substitution, and such shifts may change the labor-intensity of production, resulting in employment impacts that are not proportional to output changes (EPA, 2010a). The lack of resource constraints or substitution effects that occur over the longer run also mean that I-O models tend to overestimate the employment effects of a policy (EPA, 2010a).

Studies that rely on I-O models calculate some combination of direct, indirect, and induced effects. Direct effects are the changes in output that result from an increase in the cost of inputs (e.g., fuel) in regulated sectors, using the fixed, proportional relationship mentioned above. Indirect effects are calculated by using the I-O relationship between outputs in directly affected sectors and required inputs in related sectors (e.g., suppliers). Induced effects are general re-spending effects that result from subsequent changes in household income. The I-O approach does not necessarily account for positive shifts in economic activity towards the pollution abatement sector when the directly regulated sector is expected to purchase pollution abatement equipment or services to comply with the regulation (though in some cases, this effect was approximated in the studies by supplying information on required pollution abatement equipment as an input into an I-O model).

#### *Induced Effects*

Most of the I-O based studies in Table 4 did not specify the re-spending multipliers used to estimate induced effects.<sup>19</sup> We interpret this as an indication that they relied on the default option in the I-O model, which often assumes linearity in effects. In at least one case, the authors departed from this approach. Bivens (2015) chose 0.5 as the re-spending multiplier based on a review of the empirical literature. He also indexed hourly wages by industry such that the induced effects in an industry with above-average wages were higher than those from an industry with below-average wages.

Including induced effects often significantly increased estimated employment effects from a regulation. For instance, Global Insight IHS (2010) and Cicchetti (2011) estimated that about one-third of net jobs lost or gained due to regulation stemmed from induced effects (see section 4.2.4 regarding how “jobs” are measured and reported from these studies). Only two of the I-O studies in Table 4 restricted themselves to direct and indirect employment impacts (Busch, et al. 2012; U. Mass., PERI, et al. 2011).<sup>20</sup> The Busch, et al. (2012) study noted that it did not estimate aggregate employment impacts because “to do so would require complicated assessments of the indirect effects on vehicles miles traveled and gasoline consumption,” in other words, effects on consumer behavior. See Section 5.3.5 for a brief summary of other potential limitations of I-O models for assessing the effects of national policy from the academic literature.

Moving on from discussing induced effects, it is difficult to parse the degree to which an I-O approach may overstate effects compared to a model that incorporates macroeconomic feedbacks. The results from two studies of proposed greenhouse gas emission standards for existing power plants under the Clean Power Plan - Bivens (2015) and Industrial Economics (IeC) and Inter-industry Economic Research Fund (IeC and IERF) (2015) – may offer some insight in this regard. Both studies examined roughly similar policy scenarios and used similar input assumptions.<sup>21</sup> However, Bivens used an I-O approach supplemented by separate econometric estimates to capture electricity price effects,<sup>22</sup> while IeC and IERF (2015) relied on the I-O macro-econometric model, Inforum LIFT. Ignoring the electricity price

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<sup>19</sup> There are a variety of ways to calculate induced income or employment effects. IMPLAN’s default multiplier (referred to as Type II, which includes direct, indirect, and induced effects) assumes a linear relationship between total income and household expenditures (i.e., each dollar of income generated from working is spent on good and services as dictated by the input-output matrix). However, it is possible to specify a multiplier in which only a portion of the total income generated from labor is spent (i.e., distinguishing disposable from total income) as in the RIMS I-O model. A multiplier may also adjust for differences in household spending by income category.

<sup>20</sup> Induced effects are viewed as particularly uncertain. Grady and Muller (1988) recommend against considering induced effects since price responses and other macroeconomic feedbacks (including government stabilization policies) that are not considered in an I-O model would likely counteract some of these effects.

<sup>21</sup> Both studies use cost estimates and information on retirements and new capacity from EPA’s analysis. The policy scenarios analyzed are slightly different: Bivens (2015) averages EPA’s direct employment estimates from four proposed approaches that vary in stringency and pace as well as whether standards are met through a state-by-state or regional approach, while IeC and IERF (2015) only evaluate a regional approach. However, EPA’s direct employment estimates only differ by about 10% in 2025 across scenarios and by less than that for 2020.

<sup>22</sup> Bivens (2015) examines employment effects from a change in the price of electricity using two different regression techniques: vector auto regression (VAR) and a state-level panel difference-in-difference approach. The VAR regressions simulate the effect of an electricity price shock to see how employment responds. He interprets the result as a short run effect that will likely decline with time. He averages the results from these two approaches to derive a point estimate for 2020 only.

increase effects, Bivens (2015) estimated additional “jobs” in 2020 that are almost five times higher than those estimated by IeC and IERF (2015) for the same policy. (See section 4.3 regarding how “jobs” are measured and reported from these studies.)

#### *4.1.3 I-O Based Macro-Econometric Modeling*

I-O based macro-econometric models integrate the high level of detail from an input-output model with the forecasting properties of a macro-econometric forecasting model (U.S. EPA, 2010a). Unlike I-O models, this approach accounts for supply-demand conditions in the economy, including resource constraints, through a series of accounting (e.g., savings equal investment) and econometrically estimated relationships (Hahn and Hird, 1991). Feedbacks between supply and demand occur via macro-econometric equations (CGE models accomplish this via a price mechanism and market clearing assumptions) (West, 1995). The predictions generated by this type of model “are integrated and simultaneously determined....price increases in one sector are translated into cost and price increases in other sectors” (Portney, 1981). This is a key advantage over I-O models that assume away these effects. In addition, I-O macro-econometric models can estimate changes in demand for and production of intermediate goods due to their coupling with a detailed input-output model.

While CGEs assume full market clearing, I-O macro-econometric models assume imperfect knowledge of product and factor markets, with an emphasis on tracking short run disequilibrium – such as business cycles or cyclical unemployment - over time (West, 1995; EPA, 2010a). In the long run, I-O macro-econometric models are consistent with neoclassical growth theory in that supply side effects dominate model outcomes (Arora, 2013). For instance, after a policy shock is introduced into the Inforum LIFT model, the economy may depart from its long-term growth path and the steady-state rate of unemployment, but eventually it returns to this path/rate (IeC and IERF, 2015).

We found only two instances where an I-O macro-econometric model was used to evaluate economic impacts for a specific EPA air regulation. IeC and IERF (2015) used the Inforum LIFT model to examine the employment impacts of the Clean Power Plan, while Meade (2009) used the same model to examine the sectoral impacts of fuel economy standards for light-duty vehicles and the renewable fuels standard as mandated under the Energy Independence and Security Act. In the IeC and IERF (2015) study, employment estimates from the Inforum LIFT model were supplemented based on detailed information from EPA’s electricity dispatch model, IPM, and other expert sources to account for the effects of new capacity, plant retirements, and pollution control retrofit installations. Meade (2009) supplemented the standard Inforum LIFT model with an ethanol sub-module to capture specifics of the ethanol industry.

## **4.2 Assumptions and Policy Scenarios**

A frequent purpose of the studies included in Table 4 is to revisit the underlying assumptions of EPA analyses, most of which do not rely on economy-wide modeling approaches (See Section 3). It is not uncommon for outside organizations to utilize different compliance costs, vary the timeline under which regulatory requirements come into place, or assume that requirements would apply to a broader or narrower set of entities than assumed by EPA. Of the studies in Table 4, more than 70 percent used

assumptions that varied, often substantially, from those used by EPA. Unfortunately, it is relatively rare for these studies to evaluate the relative sensitivity of their results to the revised assumptions.<sup>23,24</sup> NERA (2012) is an exception: In one scenario, it used EPA annualized cost estimates for compliance with the Ozone NAAQS and assumed they would occur in the year in which attainment is required; in another scenario, it used these same cost estimates but assumed that they were all capital costs and would occur both before and in the year in which compliance is required. Results for these scenarios were presented side-by-side to demonstrate differences in required retrofits, electricity sector costs, and annual energy market and labor market impacts.

It can be difficult to parse the effects of different input assumptions from the effects of modeling approach. For instance, NERA (2011b) and U. Mass., Political Economy Research Institute (PERI), et al. (2011) examined the combined effects of the Utility MACT and Transport rules on employment. NERA (2011b) relied on a combination of different partial equilibrium models to approximate economy-wide effects, while U. Mass., PERI (2011) used the IMPLAN input-output model. Both studies also explored alternate assumptions with regard to compliance technologies, expected coal unit retirements, and new capacity relative to what EPA utilized. In one instance, employment was estimated to decline by 1.4 million job-years between 2013 and 2020 (NERA 2011b); in the other, it was estimated to increase by 1.46 million job-years between 2010 and 2015 (U. Mass., PERI 2011). It is unclear to what degree this large difference in results is driven by alternate assumptions or the use of different models that also may have different assumptions embedded in them.

Of the studies included in Table 4, approximately 65% also evaluated alternative ways in which a regulation could be implemented. At times, these studies evaluated the EPA proposed option but also included several additional scenarios. For instance, Global Insight IHS (2010) examined three different ways in which the Boiler MACT could be implemented: one in which all proposed source-type standards are imposed on coal, biomass, liquid and natural gas 2 boilers; one in which only HCl standards are imposed on this universe; and a third option in which all proposed source-type standards are imposed on natural gas boilers (Gas1 units are not covered by the rule) but as emission limits instead of as work practice standards as proposed by EPA. Likewise, NERA (2016) examined the effect of five different trading regimes under rate and mass based approaches for the Clean Power Plan model rule in addition to the two analyzed by EPA.

#### 4.3 Metrics Used to Report Employment-Related Economic Impacts

Table 5 summarizes the metrics used by the subset of outside organization studies that examined the employment effects of an EPA air regulation. In addition, we include two EPA regulatory analyses that

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<sup>23</sup> The Institute for Policy Integrity (IPI) (2012) criticized these analyses, stating that they are “extremely sensitive to data and model structure, but in policy discussions the underlying assumptions and limitations of the models are inconsistently reported and too often ignored.”

<sup>24</sup> An example outside of the air context is instructive: Veritas Economic Consulting (2011) and Ackerman (2011) arrived at markedly different estimates of employment impacts for the coal combustion residuals (CCR) proposed regulation promulgated under RCRA in spite of using the same modeling approach, the IMPLAN input-output model, to evaluate the same policy option. Veritas Economic Consulting (2011) estimated job losses of 184,000 to 316,000. Using alternate assumptions, Ackerman (2011) estimated a net gain of 28,000 jobs.

relied on a CGE model to evaluate employment (i.e., the 2005 final CAIR and BART regulations). Table 5 is first organized by model type and then date. Studies that used CGE-based models appear first, followed by those using I-O models, I-O macro-econometric models, and, finally, combined PE and engineering model approaches. As previously mentioned, most of the fifteen studies of employment impacts conducted or sponsored by outside organizations used either a CGE or I-O modeling approach.

Every outside organization study included in Table 5 expressed results in terms of changes in the number of “jobs,” “job-years,” or “job equivalents” relative to a baseline or reference case. Occasionally, the change in employment was also reported in terms of percent change. EPA expressed estimates in terms of “percent change in labor inputs.” Eight of the studies also reported information on changes in wage rates or labor income. Studies varied in the extent to which the employment metrics utilized were clearly defined. Some used the terms job or job-years without offering a clear definition (e.g., Busch, et al., 2012; NERA, 2011b; Cichetti, 2011). IeC and IERF (2015) reported changes in employment by industry in terms of “jobs,” defined as “total hours divided by average hours worked per employee.” Others converted changes in wages or labor income into number of jobs. For example, Goldberg (2011) defined a job as “sufficient wages to employ one person full time for one year in a given sector.”

Recall that in a CGE model, because the labor market is in equilibrium, any changes in employment are “voluntary.” A representative agent chooses how much to work “based on the utility of his real wage and the disutility of work” (OECD 2004). A CGE model can generate as an output changes in wage income and/or hours worked as a result of a policy change but does not directly report jobs lost or gained. Studies that used the NewERA CGE model converted outcomes from the CGE model into a “job-equivalent,” defined as the change in labor income divided by the annual baseline income for the average job or “the equivalent number of average jobs that such labor payments would fund under baseline wage rates” (Chamber of Commerce (COC) and NERA, 2013; NERA, 2014b; NERA, 2015c). These studies also reported the total net change in wages or labor income, though the wage or income from an average job used in the calculations of job equivalents was not reported. In several of these studies, NERA noted that “a loss of one job-equivalent does not necessarily mean one fewer employed person—it may be manifested as a combination of fewer people working and less income per worker” (NERA, 2014b). However, converting voluntary changes in labor/leisure in response to wage changes to a “loss of job-equivalents,” could confuse readers who may misinterpret this metric as an indication of involuntary changes in employment, which are not captured by the model.

Studies that reported estimates of jobs lost or gained have been criticized for their lack of explanation “of what type of estimate has been performed, or the limitations of that particular type of estimate” (COC and NERA, 2013). Most of the studies included in Table 5 were clear about the main technique or approach utilized, at times including detailed documentation about the model itself, but many reported results without any discussion of how the estimates should be interpreted or what limitations or caveats might apply. For instance, a key piece of information that is often left unreported is whether jobs are full-time equivalents or do not distinguish between full- or part-time employment. It is also often difficult to understand if an estimated change in employment is relatively large or small. Seven of the 17 studies reported information in terms of percent change. Of those that reported changes in number of jobs or level of wages/income, only four also included information on baseline employment or wages.

In general, the studies that estimate labor market effects using a CGE model or I-O macro-econometric model tended to offer some guidance regarding how results should be interpreted. Six of the seven studies that used CGE models noted the assumption of full employment and characterized reported changes in labor income as resulting from (1) changes in the real wage, and (2) voluntary changes in the number of hours worked in response to changes in the real wage. EPA (2005a, 2005b) was careful to note that changes in “the number of productivity-adjusted hours of labor supplied by households... is not the same as estimating jobs or employment.” With regard to the limitations of an estimate, only three of the seven studies that utilized I-O models signaled or discussed the possibility of overestimating effects. Global Insight IHS (2010) characterized its estimates as jobs potentially at risk and noted that “not all these jobs will be eliminated because costs may be absorbed in different ways and some may be passed onto consumer.” Bivens (2015) noted that large changes in employment are likely to be counteracted by a response from the Federal Reserve. Of the five I-O studies that included induced effects, only two reported them separately from direct and indirect effects (recall that two I-O studies did not report induced effects).<sup>25, 26</sup>

Finally, an important distinction, particularly when comparing partial and general equilibrium approaches, is whether a study measures net employment impacts or a gross measure of impacts. A net estimate accounts for various direct and indirect effects of introducing a new regulation on labor and includes both positive and negative impacts across sectors. A gross estimate may quantify employment impacts in sectors that supply pollution abatement equipment but not consider how this increase in economic activity affects labor in other related sectors; and/or it may estimate employment impacts in regulated sectors but does not examine the extent to which labor shifts to other sectors.

Of the studies included in Table 5, all of the CGE-based studies characterized their estimates as net effects. Four of the seven studies that relied on I-O models also claimed to report net effects because they examined more than just the effect of an increase in compliance costs; for instance, they may have included employment effects in sectors that supply pollution control equipment or that stem from changes in energy prices. However, since most I-O models ignore substitution and displacement effects that operate through changes in prices, it is not clear to what extent employment estimates derived from this class of models should be considered a truly net measure.

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<sup>25</sup> One study explored the possibility that the U.S. only captures a portion of the additional jobs created based on the degree to which it is able to lead in advanced vehicle technology manufacturing (Baum and Luria, 2010).

<sup>26</sup> Bivens (2015) also examined the socioeconomic characteristics of employees in winning versus losing industries, including average wage, to highlight potential challenges for workers transitioning out of one industry and into another. U. Mass, PERI, et al. (2011) is the only study that separately reports short-term construction and installation employment (measured in job-years, or one year of full-time employment) in addition to permanent operations or maintenance employment (measured as jobs).

**Table 5: Metrics used to Measure Potential Employment Effects of EPA Regulations**

<b>AUTHOR</b>	<b>MODEL TYPE</b>	<b>METRICS REPORTED</b>	<b>BASELINE EMPLOYMENT REPORTED?</b>	<b>OTHER INFORMATION/CAVEATS</b>
<b>NERA (2015C)</b>	CGE	- % change in real wage rate - % change in labor income - Change in annual job-equivalents	Y	Includes same definitions and main caveats as NERA (2012)
<b>NERA (2014B)</b>	CGE	- % change in real wage rate - % change in labor income - Change in annual job-equivalents	Y	Includes same definitions and main caveats as NERA (2012)
<b>COC AND NERA (2013)</b>	CGE	- % change in labor income (not reported for each regulation analyzed) - Change in job-equivalents	N	Net effects including increased labor demand in pollution control equipment sectors. Long-run equilibrium model with full employment so does not include transitional effects.  Includes same definitions and main caveats as NERA (2012)
<b>NERA (2012)</b>	CGE	- Labor income loss - Change in annual job-equivalents	N	Job-equivalent: “total labor income change divided by the annual income for the average job.”  Labor income impacts include: changes in real wage per hour worked, and voluntary changes in hours worked in response to changes in real wages.  “A loss of one job-equivalent does not necessarily mean one less employed person—it may be manifested as a combination of fewer people working and less income per person who is working.”
<b>SMITH, ET AL. (2012)</b>	CGE	- Translate estimated loss in income equivalent to x number of full-time jobs	N	Note this is a net effect, “inclusive of job gains associated with installing retrofits and building new power plants.”  * Does not define a job equivalent or include caveats regarding the use of this metric.
<b>EPA (2005A)</b>	CGE	- Percent change in labor inputs	N	CGE models typically consider how policies influence labor markets “through how they alter the number of productivity-adjusted hours of labor supplied by households (this is not the same as estimating jobs or employment).”

AUTHOR	MODEL TYPE	METRICS REPORTED	BASELINE EMPLOYMENT REPORTED?	OTHER INFORMATION/CAVEATS
				Full-employment model: "households choose between labor and leisure based on income and substitution effects."  "People are choosing to work slightly fewer hours in response to small declines in real wage rates, rather than work more hours to offset additional costs of purchasing goods"
<b>EPA (2005B)</b>	CGE	- Percent change in labor inputs	N	Identical discussion to EPA (2005a)  "People are choosing to work slightly more hours to offset additional costs of purchasing goods"
<b>BIVENS (2015)</b>	IO + VAR	- Direct + indirect jobs - Socioeconomic characteristics of employees in gaining vs. losing industries	N	In well-functioning economy without slack in labor market any significant change in economy-wide employment would "likely be met by a countervailing response from the Federal Reserve," so net employment response would be zero  Separately reports induced effects.
<b>BUSCH, ET AL. (2012)</b>	IO	- Net change in employment, both in number of jobs and % change, overall and by sector - Overall % change in wages	N	Acknowledges that dynamic IO model is not GE approach; includes labor productivity adjustments over time but model is less sophisticated in its treatment of price changes than CGE  "The idea that markets should always be forced to equilibrium by price changes is debatable. While mathematically convenient, evidence of disequilibrium abounds. Further, more complicated forecasting methods have not been found to be more accurate than simpler ones."
<b>CICCHETTI (2011)</b>	IO	- Added jobs or job increases	N	Includes evaluation of employment effects from health improvements  Separately reports induced effects
<b>U. MASS, PERI, ET AL. (2011)</b>	IO	- Net full-time jobs - Annual job-years	N	Distinguishes between short term construction employment (in annual job-years or one year of full-time employment) and permanent operation/maintenance jobs (full-time jobs)
<b>GOLDBERG (2011)</b>	IO	- Net contribution to employment base (jobs)	N	Define a job as sufficient wages to employ one person full time for one year in a given sector.

AUTHOR	MODEL TYPE	METRICS REPORTED	BASELINE EMPLOYMENT REPORTED?	OTHER INFORMATION/CAVEATS
		- Net gain in wage and salary compensation		
<b>GLOBAL INSIGHT IHS (2010)</b>	IO	- Number of jobs potentially “at risk” - Changes in labor income, value added	N	Notes that not all these jobs will be eliminated because costs may be absorbed in different ways and some may be passed onto consumers  Separately reports induced effects
<b>BAUM AND LURIA (2010)</b>	IO	- U.S. jobs created, relative to 2008, by technology	Y	Range based on varying assumption of how much U.S. leads on advanced vehicle technologies versus a percent of these jobs going abroad
<b>IEC AND IERF (2015)</b>	IO-macro-econometric	- Increase of “up to x jobs” - Percentage change in employment by sector	Y	Employment or “jobs” are defined as total hours divided by average hours worked per employee.
<b>NERA (2011A)</b>	Combine PE/eng. models	- Change in average annual (i.e., jobs) and cumulative (i.e., job-years) employment - Change in overall and per household disposable income	N	Includes jobs created in pollution control sectors and jobs lost due to higher electricity prices  Does not account for potential productivity or growth effects due to financing of pollution control expenditures; does not presume use of unemployed or idle resources  Assumes consumers can reduce the impact of higher prices by shifting away from more expensive energy
<b>NERA (2011B)</b>	Combine PE/eng. models	- Job-years (in text) over study period and jobs (in graphic)	N	

## 5. Economy-Wide Approaches to Estimating Economic Impacts in the Literature

The previous two sections summarize the use of CGE and other economy-wide modeling frameworks to analyze the economic impacts of an air regulation. Also of interest, however, are current practice and state-of-the-art modeling that pertain to the estimation of economic impacts from environmental regulation in the academic literature. Section 5.1 discusses available theory, evidence on labor market impacts, and treatment in CGE and other economy wide modeling frameworks. Section 5.2 describes key issues when representing capital markets in U.S. CGE models. Section 5.3 discusses sectoral impacts. Section 5.4 describes how energy price changes might manifest in the economy in response to regulation and key aspects of capturing energy markets in CGE models. Finally, section 5.5 discusses how CGE models have been used to evaluate impacts on households differentiated by income.

### 5.1 Labor market impacts

The Office of Management and Budget (OMB) suggests regulatory agencies consider, to the extent feasible, employment effects, whether positive or negative (OMB, 2015).<sup>27</sup> However, OMB also notes that: “Some regulations can have adverse effects ..., whereas other regulations might produce benefits. The relevant effects can be quite complex, since in general equilibrium, regulation in one area can have ripple effects across many markets, making it difficult to produce aggregate figures.” It adds that, “isolating the effect of environmental regulation on employment is further complicated by the fact that changes in other economic conditions (e.g. recessions, import competition, tax policy) also affect employment over time and across sectors.” Additionally, “only a small fraction of individual regulations or agency actions will have a large enough effect to allow for measurement of changes in ... national employment” (OMB, 2015). Finally, OMB outlines several potential pitfalls when assessing the employment effects of regulations: expecting a precise, measurable impact from most individual regulations, ignoring long-run or indirect impacts, and ignoring the importance of timing (OMB, 2015).

Recognizing the analytic challenges posed by such an analysis, EPA tailors its employment analyses to the specifics of each regulation. In some cases, EPA focuses on a qualitative discussion of employment impacts – both positive and negative –; in other cases, EPA quantifies selected employment impacts in the regulated, environmental protection, and relevant related sectors for which it has scientifically defensible methodologies and high quality data. In all cases, EPA strives to transparently discuss the strengths and limitations of analytic methods and data utilized. As described in Section 3, EPA analyses that quantify employment impacts primarily rely on a bottom-up, engineering-cost approach.

This section first describes what economic theory predicts with regard to labor market impacts in the context of environmental regulation. Next, this section briefly reviews the peer-reviewed, published economic literature on environmental regulations and labor market impacts, most of which has been ex-post evaluation using partial equilibrium micro-econometric techniques. In the context of economy-wide modeling, we review how labor markets are typically structured in a CGE model as well as alternative

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<sup>27</sup> See Section 1 for specific language in Executive Order 13563 relevant to estimating employment effects.

approaches used to-date. Finally, this section briefly describes the literature related to the use of economy-wide modeling approaches aside from CGE for examining labor market impacts of environmental policy.

### *5.1.1 Theory: Air Regulations and Labor Markets*

The overall impacts of an air regulation on employment are difficult to disentangle from other economic changes and conditions that affect employment -- over time, across regions, and across industries. Microeconomic theory describes how firms adjust their use of inputs in response to changes in economic conditions. Labor is one input into production, along with land, capital, energy, and materials. In competitive markets, firms choose inputs and outputs to maximize profit as a function of market prices and technological constraints. Berman and Bui (2001) have tailored one version of the standard neoclassical model to analyze how environmental regulations affect labor demand decisions, where the change in a firm's labor demand arising from a change in regulation is decomposed into an output effect and a substitution effect.<sup>28</sup> The output effect describes how, if labor-intensity of production is held constant, a decrease in output generally leads to a decrease in labor demand. However, as noted by Berman and Bui, although it is often assumed that regulation increases marginal cost, and thereby reduces output, it need not be the case. A regulation could induce a firm to upgrade to less polluting, and more efficient equipment that lowers marginal production costs. In such a case, a firm's output could theoretically increase. The substitution effect describes how, holding output constant, regulation affects the labor-intensity of a firm's production. Although increased regulation generally results in higher utilization of production factors such as pollution control equipment and energy to operate that equipment, the resulting impact on labor demand is ambiguous. For example, equipment inspection requirements, specialized waste handling, or pollution technologies that alter the production process may affect the number of workers needed to produce a unit of output. As the output and substitution effects may be both positive, both negative or some combination, standard microeconomic theory alone cannot definitely predict the sign of the net effect of regulation on labor demand at regulated firms.

If the U.S. economy is at full employment, even a large-scale air regulation is unlikely to have a noticeable impact on aggregate net employment. Instead, labor in affected sectors would primarily be reallocated from one productive use to another (e.g., from producing electricity or steel to producing high efficiency equipment), and net national employment effects from regulation would be small and transitory (e.g., as workers move from one job to another) (Arrow, et al. 1996). If the economy is operating at less than full employment, economic theory does not clearly indicate either magnitude or direction of the net impact on employment (Schmalensee and Stavins, 2011). For example, the CBO identified MATS and air regulations for industrial boilers and process heaters as potentially leading to short-run net increases in economic growth and employment, driven by capital investments to comply with the regulations (CBO, 2011). An important fundamental research question is how to accommodate unemployment as a structural feature in economic models. This feature may be important in evaluating the impact of large-scale regulation on employment and wages (Smith, 2012).

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<sup>28</sup> Morgenstern, Pizer, and Shih (2002) developed a very similar model.

Even at full employment affected sectors may experience transitory effects as workers change jobs. For example, some workers may need to retrain or relocate in anticipation of the new requirements or require time to search for new jobs, while shortages in some sectors or regions could bid up wages to attract workers. It is important to recognize that these adjustment costs can entail local labor disruptions, and although the net change in the national workforce is expected to be small, localized changes in employment can still have negative impacts on some individuals and communities and positive impacts on others. However, most long-run equilibrium models do not consider such transitory effects, which raises the question of how to analyze these effects in an economy-wide setting.

Because an air regulation also shifts economic activity away from more- towards less-polluting activities, net employment impacts are composed of a mix of potential declines and gains in different sectors of the economy. In addition to changes to labor demand in the regulated industry, net employment impacts encompass changes within sectors that produce pollution abatement equipment and services, and, potentially in other sectors, including upstream or downstream from the regulated sector. In fact, air regulations often increase demand for pollution control equipment and services needed for compliance – for example building, installing and operating scrubbers. This will increase the demand for many inputs (e.g., steel, cement, blowers, pumps) and may increase employment in these upstream industries. Moreover, a regulation that increases the costs of a primary input such as electricity may cause a decrease in the demand for labor in energy-intensive industries, such as pulp and paper and aluminum manufacturing. Therefore, it is potentially important to consider the net effect of compliance actions on employment across multiple sectors or industries.

Environmental regulation may also affect labor supply and productivity or employees' ability to work. While the theoretical framework for analyzing labor supply and productivity effects is analogous to that for labor demand, it is more difficult to study empirically. There is a small emerging literature that uses detailed labor and environmental data to assess these impacts.<sup>29</sup>

### *5.1.2 Micro-econometric Empirical Literature: Air Regulations and Labor Markets*

The labor economics literature contains an extensive body of peer-reviewed empirical work analyzing various aspects of labor demand based on the theoretical framework discussed in the previous section.<sup>30</sup> This work focuses primarily on effects of labor market policies such as labor taxes and minimum wages.<sup>31</sup> In contrast, the peer-reviewed literature estimating employment effects of environmental regulations, while growing, is relatively limited. It relies mainly on micro-econometric techniques and historical data to examine the ex-post impacts of regulations that have already been implemented.

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<sup>29</sup> Although this literature faces empirical challenges, researchers have found that air quality improvements lead to reductions in lost work days (e.g., Ostro, 1987). Moreover, there is limited evidence that suggests worker productivity may also improve with better ambient air quality. Graff Zivin and Neidell (2012) used detailed worker-level productivity data from 2009 and 2010, paired with local ozone air quality monitoring data for a large California farm growing multiple crops that pays workers on a piece-rate basis. They find that “ozone levels well below federal air quality standards have a significant impact on productivity: a 10 parts per billion (ppb) decrease in ozone concentrations increases worker productivity by 5.5 percent.” (Graff Zivin and Neidell, 2012, p. 3654).

<sup>30</sup> See Hamermesh (1993) for a detailed treatment

<sup>31</sup> See Ehrenberg and Smith (2000), Chapter 4: “Employment Effects: Empirical Estimates” for a concise overview.

Overall, the peer-reviewed literature does not contain evidence that air regulations have had a large impact on net employment in the regulated sector (either negative or positive), and generally does not speak to the sign or magnitude of the overall effect of regulation on the U.S. labor market outside of directly affected sectors. Berman and Bui (2001) examined the impact of local air quality regulations in Los Angeles on employment in regulated manufacturing industries relative to similar plants that did not face the same regulations. They found that even though regulations impose large costs on plants, they had a small, insignificant effect on employment. Ferris, et al. (2014) also used a quasi-experimental empirical approach, and found that, relative to similar but unregulated plants, employment impacts from Phase I of EPA's Title IV Acid Rain Program were close to zero for regulated utilities. Gray, et al. (2014) found that pulp mills subject to air and water regulations in EPA's 1998 Cluster rule experienced relatively small, and not always statistically significant, decreases in employment.

Other research on employment effects in regulated sectors, such as Greenstone (2002) and Walker (2011, 2013), suggest that counties subject to stricter air quality regulation may generate fewer manufacturing jobs than less regulated ones. However, because they identified employment impacts by comparing non-attainment to similar attainment areas, employment impacts are likely overstated; they are "double counted" to the extent that regulation caused plants to locate in one area of the country rather than another (Greenstone, 2002). List et al. (2003) found some evidence that this type of geographic relocation may be occurring. Kahn and Mansur (2013) examined manufacturing employment impacts of air regulations by pairing a regulated county with a neighboring, less regulated county, while controlling for differences in electricity price and labor regulation. They found limited evidence that air regulations caused employment to be lower on net within a county-border-pair. While regulation may cause an effective relocation of labor across a county border, since one county's loss is another's gain, such shifts cannot be transformed into an estimate of a national net impact on employment.

If indirect employment impacts are expected to be significant, a PE approach would understate the net employment impacts of an air regulation. As pointed out by Greenstone (2002), a PE approach may also potentially double count some effects. Hafstead and Williams (2016) noted that "to the extent that regulation affects employment in ... other industries, such studies can't measure the overall effect.... Addressing those issues requires a general-equilibrium analysis. But existing general equilibrium models used to analyze environmental regulation almost always assume full employment. And the few models in this area that do allow for unemployment typically focus on types of unemployment that are largely unimportant in the United States (e.g., unemployment caused by strong unions that negotiate wages well above free-market levels)."

As yet, there also is no consensus in labor economics regarding the use of general equilibrium models to estimate the labor market impacts of specific employment policies, which leaves open the question of their potential value added to estimate labor market impacts of air regulations relative to PE approaches. An overview of the labor literature observed that "from the empirical point of view, the great majority of studies have looked only at the direct effects of labor market policies, neglecting their effects on the general equilibrium of the economy. ... In the United States, the amounts budgeted for

employment policy are relatively small, so it seems reasonable to assume that their macroeconomic effects are negligible.” (Cahuc and Zylberberg, 2004). Heckman, et al. (1999) suggested that general equilibrium studies of labor market policies may be more informative than PE studies when these programs substantially impact the economy and when non-participants are expected to be significantly affected by the program.

In the next three sections, we consider economy-wide models as a potential tool to estimate labor market impacts of an air regulation. We describe the way labor markets are typically structured in CGE models (section 5.1.3); discuss examples in the literature where alternative approaches have been implemented in a CGE framework, particularly in an environmental context (section 5.1.4); and then briefly examine the extent to which other types of economy-wide models may add value when examining labor market effects (section 5.1.5).

### *5.1.3 Standard treatment of labor markets in CGE models*

Boeters and Savard (2013) observed that, “If we look at the body of computable general equilibrium (CGE) literature as a whole, the labor market has certainly not been one of the main points of attention. In fact, many of the classical CGE studies in the areas of trade liberalization, tax analysis and climate policy work with the simplest possible set of assumptions about the labor market: labor supply is fixed and a uniform, flexible, market-clearing wage balances labor supply and demand.” With these assumptions, workers may move from one sector to another following a policy shock, but the economy remains at full employment.

While keeping the assumption of a representative household and a flexible, market-clearing wage, many CGE models have since been updated to allow the labor supply to adjust endogenously following changes in the real wage and/or non-wage income. In fact, US REGEN is the only model among the seven U.S. CGE models described in Table 6 in that retains the assumption of a fixed labor supply.

To allow labor supply to adjust, a representative household is assumed to maximize a utility function that includes goods and leisure. Responsiveness of the labor supply to changes in the real wage and non-wage income is calibrated to empirically estimated parameters.<sup>32</sup> While labor supply is endogenous, changes are voluntary; involuntary unemployment is still not determined within the model. Recall that voluntary unemployment reflects changes in workers’ labor-leisure choices in response to changes in the wage rate (i.e., when their reservation wage is higher than the prevailing wage they will choose to consume more leisure). Involuntary unemployment exists when a worker is willing to work at the prevailing wage rate but is unable to secure employment.

Labor supply elasticities are important parameters in these models. The uncompensated labor supply elasticity consists of two components, the substitution effect and the income effect. The substitution effect is positive as, ceteris paribus, workers will increase hours worked (and consumption) with an increase in the wage. This is reflected in the positive sign of the compensated labor supply elasticity.

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<sup>32</sup> Calibration is discussed in Fox (2002) and van Leeuwen (2010).

The income effect is equal to the income elasticity of labor supply, which reflects how hours worked react to a change in non-wage income, multiplied by the share of total income from wages. As leisure is a normal good, the income elasticity is generally negative, as is the income effect.

The sign and magnitude of the change in labor supply following a policy shock will depend on the relative magnitudes of the substitution and income effects. As discussed in the social cost white paper, a productivity shock that reduces returns to both labor and capital may result in an *increase* in labor supplied (this was observed in a number of simulations using the EMPAX-S CGE model).

Five of the seven U.S. CGE models described in Table 6 are calibrated to uncompensated and compensated labor supply elasticities that fall within ranges reported in a literature survey conducted by CBO (1996). Recently, CBO re-reviewed the empirical literature related to measuring the substitution effect and found lower estimates than previously (McClelland and Mok 2012). Of the four models that calibrate to the literature, one is outside the revised range, two are at its upper bound, and one is within the range. IGEM is unique in that the labor supply elasticities are estimated, along with the demand system, from the same time-series data set (Jorgenson et al. 2013); they fall outside the ranges presented in both CBO reports (i.e., CBO, 1996; McClelland and Mok, 2012). Since the labor supply is fixed in the US REGEN model, it does not require labor supply elasticities.

**Table 6: Labor Supply Elasticities: Comparing the Literature to Single-Country U.S. CGE Models**

	<b>Total/ Uncompensated</b>	<b>Substitution/ Compensated</b>	<b>Income</b>
<b>CBO (1996)</b>	0 to 0.30	0.20 to 0.40	-0.20 to -0.10
<b>McClelland and Mok (2012)</b>		0.10 to 0.30	-0.10 to 0
<b>ADAGE-US</b>	0.15	0.40	
<b>EMPAX</b>	0.15	0.40	
<b>IGEM</b>	-0.03	0.70	
<b>NewERA</b>	0.05	0.25	
<b>USAGE-ITC</b>	0.10	0.30	
<b>USREP</b>	0.10	0.30	
<b>US REGEN</b>	n/a	n/a	

Notes: Elasticities for models were obtained from available documentation or from the model developers.

The assumption of a single representative household can be relaxed and expanded to multiple household types along several dimensions. These can include skill type (e.g. high and low skilled

workers), location (e.g. rural and urban households), and income type (e.g. laborers, capital owners).<sup>33</sup> Several U.S. CGE models also include multiple regions, with each region having one or more representative household. In these models, workers are generally assumed to not move between regions. A potential difficulty in differentiating by household and/or region is obtaining suitable data and elasticities to parameterize a model, which Boeters and Savard (2013) point out are not typically available from existing studies.

Although less common in environmental applications, another alternative for modeling labor supply is microsimulation. Microsimulation uses microdata of individual households directly (often from the U.S. Consumer Expenditure Survey) rather than aggregating them into representative households. Implementation requires linking the micro module with the CGE model, either through a one- or two-way linkage. IGEM uses this approach (Jorgenson et al. 2013). USREP has also been paired with a microsimulation model in some applications (Rausch et al. 2011, Rausch and Rutherford, 2010). In both cases, the models continue to maintain a fairly standard treatment of the labor market. (See section 5.5 for further discussion of the use of microsimulation approaches in CGE models to evaluate economic impacts on households based on income.)

Labor demand in CGE models is generally derived in a straightforward manner from the model's sectoral production functions, often nested CES or, in some cases, translog functions. If there are multiple household types on the supply side, they may be matched on the demand side one-for-one or added up into an aggregate. As with labor supply, a potential difficulty in implementing additional dimensions is in obtaining suitable data and elasticities for parameterization.

CGE models generally do not model the transition dynamics from one equilibrium to another. By construct, they are medium- to long-run models that characterize equilibrium before and after the policy shock. As such, the labor market clears instantaneously in response to a new set of prices and quantities resulting from the shock. A few dynamic CGE models include transitional periods of labor market disequilibrium. For example, in the G-Cubed multi-country model, long-run wages adjust to move each region to full employment, but employment can be above or below the long-run equilibrium level in the short run (McKibbin and Wilcoxon 2013).<sup>34</sup> The USAGE model can be equipped with an extension that includes a detailed specification of labor market dynamics (sometimes called USAGE-M), including the potential for transitional labor demand-supply imbalances (Dixon and Rimmer, 2002) that derive from the assumption that workers incur a cost due to required training, expressed in the model

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<sup>33</sup> For instance, Dissou and Sun (2013) differentiate between low and high skilled workers in a CGE model of Canada. They assume that capital and high-skilled workers are substitutes for each other (they are in the same nest of the CES function), but that low-skilled workers are less easily substitutable for capital. The MIRAGE multi-country CGE model takes a similar approach (Banse, et al., 2013).

<sup>34</sup> McKibbin and Wilcoxon (2013) are motivated by the notion that wages are fixed via contract for some segment of the employed population at any given time. As contracts expire, prices can be renegotiated, but adjustment of wages to new information is slowed by contracts still in place, which can result in short-run unemployment. This process is not represented structurally in the model, however. Instead, wages are modeled as a function of current and expected inflation and on labor demand relative to labor supply (i.e., a wage curve).

as a loss in productivity, when they change jobs or employment states (Dixon and Rimmer, 2002).<sup>35</sup> The next section discusses alternative specifications of the labor market to allow for the possibility of capturing some of the adjustment costs associated with the transition between equilibria.

#### *5.1.4 Explicit modeling of labor markets in CGE models*

One way to incorporate involuntary unemployment into CGE models as an equilibrium condition has been to use a reduced form approach consistent with the notion that frictions in the marketplace prevent wages from adjusting to their market-clearing level. Modelers often specify a wage curve, based on the empirical observation of Blanchflower and Oswald (1994), that real wages are a decreasing function of the unemployment rate. Rather than positing a single theoretical explanation, Blanchflower and Oswald (1994) presented three alternative models consistent with their empirical observation: a model of regionally based implicit contracts; an efficiency wage model; and a bargaining model (Card, 1995). In practice, the wage curve approach effectively shifts the labor supply curve inward, and while the equilibrium wage is at the intersection of the labor demand and wage curves, equilibrium employment is given by the intersection of the labor supply curve at that equilibrium wage. This approach amounts to an exogenous assumption regarding the amount of unemployment within the labor market. Therefore, attempts to use the model to estimate impacts on employment, particularly involuntary unemployment, will be dictated by the assumption regarding the magnitude of the shift in the wage curve and not by the behavior of labor markets and wage-setting within the model.

There are several recent examples of studies that have used the wage curve approach to consider employment effects in an environmental context. For instance, Dissou and Sun (2013) specified a wage curve to examine the welfare and employment implications of different ways of recycling revenues from a carbon cap-and-trade system. They found relatively small effects on employment for low and high skilled workers across scenarios, noting that this is unsurprising given that carbon-intensive industries tend to use relatively more capital than labor (i.e., as such, one would expect them to shed more capital than labor in response to the policy). Likewise, Rivers (2013) incorporated a wage curve into a highly stylized three sector static CGE model to examine the employment implications of renewable energy policies. He found that subsidies to renewable energy increase equilibrium unemployment. However, he also demonstrated that estimates of unemployment were sensitive to the inclusion of capital in the model and assumptions regarding its relative mobility. In particular, if capital bore relatively more of the burden from the policy, the real wage could rise, reducing equilibrium unemployment.

Other studies that use the wage curve approach to incorporate unemployment into a CGE model to study the effects of environmental or energy policy include Bohringer, et al. (2001), Bohringer, et al. (2012), and Bohringer, et al. (2013). Bohringer et al. (2001) built a small CGE model as a teaching tool to

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<sup>35</sup> There is also a relatively recent international trade literature that pairs empirical estimates of worker transition costs between sectors in specific countries with dynamic, structural GE trade models. The cost of switching from one sector to another is high (e.g., the few estimates available for the U.S. range from two to six times the average annual wage); workers frequently switch sectors in spite of these costs due to unobserved factors unrelated to wage differentials (Riker and Swanson 2015).

examine possibilities for green tax reform in Germany. The model allowed for multiple specifications including a closed or open economy and full employment or an equilibrium with unemployment. The authors showed that in some cases it is possible to achieve a “triple dividend:” reductions in emissions, improvement in the efficiency of the tax system, and reduced unemployment. Bohringer et al. (2012) used a CGE model to assess the labor market impacts of a feed-in-tariff policy in the electricity market in Ontario. They found that while increasing employment in “green” manufacturing, the policies had the opposite effect on employment in the rest of the economy and increased the unemployment rate overall. The authors acknowledged that external effects and technical change are ignored in their static model, and in certain cases their inclusion might produce a different outcome. Bohringer et al. (2013) used a CGE model of Germany to investigate the impacts of renewable energy promotion. They found that the possibilities for enhancing welfare and employment are quite limited, hinging crucially on the subsidy rate and financing mechanism.

As Bohringer, et al. (2005) described, “The wage curve constitutes a convenient shortcut to incorporate unemployment, but it lacks an explicit microfoundation. This makes it impossible to analyse how specific policy measures affect the wage setting mechanism. In order to track down the causal chain from policy interference to labour market effects, one must open the “black box’ of the wage curve and explicitly model the wage-setting process.” Approaches that explicitly model wage-setting mechanisms in a CGE model often involve adopting labor market models used in the labor economics literature.<sup>36</sup> There are a number of wage-setting, or wage-clearing mechanisms, including efficiency wages, collective wage-bargaining, job search and matching models, as well as explicit incorporation of other types of wage rigidities.<sup>37</sup> We briefly describe how some of these mechanisms have been incorporated into CGE models for purposes of examining the effects of environmental policy.

Dixon et al. (2011) and Babiker and Eckaus (2007) incorporated wage-rigidities into the single-country USAGE-M and the multi-region global EPPA CGE models, respectively. Dixon et al. (2011) allowed for potential disequilibrium in the labor market by specifying three states: employed, unemployed, and not in the labor force where employed labor is differentiated by industry, occupation, and region. Labor is not perfectly substitutable across all categories. For instance, those employed in occupations with less similar characteristics required more training than those employed in occupations with similar characteristics. The model also assumed a cost associated with changing employment states (Dixon and

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<sup>36</sup> Researchers also have used explicit wage-setting mechanisms in CGE models for other applications. For example, with respect to tax reform in Europe, Hutton and Ruocco (1999) include an endogenous choice between part-time and full-time employment and introduce involuntary unemployment through an efficiency wage model for full-time workers. Bettendorf, et al. (2009) and Bohringer, et al. (2005) assume wages are determined by firm–union bargaining. In addition, Bohringer, et al. (2005) assume that “each additional unit of labor is first unemployed for a certain period and may then be combined with a job according to a stochastic matching process.”

<sup>37</sup> The efficiency wage model is predicated on the idea that employers can increase worker productivity by paying above-market wages. In the collective wage-bargaining model above-market wages result from negotiations between firms and trade unions with some degree of market power. Job search-and-matching models assume that finding a job requires time and effort and is inherently stochastic. The higher the ratio of unemployed to vacancies, the lower the probability of finding a job. See Boeters and Savard (2013) for a detailed discussion of different models of unemployment and calibration issues encountered when incorporating them into a CGE model.

Rimmer, 2002). Thus, it is possible that “not everyone is doing what they want to do at the going wage rates. Some new entrants and unemployed people who offer to work in [a particular sector] cannot find a job, and some employed people [end up] working in another activity” (Dixon et al., 2011).

Babiker and Eckaus (2007) added two types of labor rigidities to the EPPA model. The rigidities affect sectoral labor mobility and sectoral wage adjustment. To implement the first rigidity, an exogenously determined fraction of sector-specific labor is not allowed to leave that sector during a period in which demand for that labor has fallen. For the second rigidity, nominal wages for sector-specific labor are fixed at the same level as in the initial period. As a result of these rigidities, climate policies can induce an excess supply of sector-specific labor and a positive rate of unemployment. The rigidities also increased costs above those for the same policy in a model without rigidities.

Recent work in the environmental arena has also focused on incorporating job search and matching models into CGE frameworks. Balistreri (2002) laid out a methodology for incorporating two salient features of the job search and matching model into a CGE framework: “(1) supplying labor for production is costly in terms of the foregone reservation wage and an individual’s chance of not being matched to a job (i.e., becoming unemployed); and (2) there is an externality by which the risk of an individual not being matched is affected by the aggregate behavior of other agents.” This second effect exacerbates cyclical changes in labor demand. He then demonstrated how this formulation of the job search and matching model operates within a dynamic CGE model of the United States when simulating a cap-and-trade policy to reduce carbon emissions. Finally, he examined the sensitivity of the unemployment results to various parameters. For instance, he showed that a higher elasticity of substitution between labor and leisure led to larger and more persistent impacts on unemployment. Likewise, the higher the share of leisure relative to labor, the larger the impact on unemployment.<sup>38</sup>

Shimer (2013) developed a simple, stylized two sector general equilibrium model, with one clean and one polluting good, and incorporated search unemployment to characterize the optimal tax rate on the dirty good. The cost of searching for a new job in the other sector combined with human capital specific to the production of only one of the two goods manifested as a loss of productivity when the worker switched jobs. He found that the optimal tax depends only on the marginal rate of substitution between the dirty good and pollution, and was therefore unaffected by any resulting reallocation of labor or the cost of switching jobs across sectors. Note that the dynamic version of the model included idiosyncratic shocks to workers’ human capital. See the next section for a discussion of dynamic stochastic general equilibrium (DSGE) models.

Finally, Hafstead and Williams (2016) developed a two-sector (one clean and one polluting) CGE model that incorporates several wage-setting mechanisms to “demonstrate a tractable framework for bringing

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<sup>38</sup> Results were also sensitive to assumptions regarding the share of initially matched workers and job turnover rates. A lower share of workers that were already matched to a job and a higher turnover rate both reduced the impacts of a policy on unemployment. In addition, higher elasticities of scale on employment resulted in larger changes in unemployment, while higher elasticities of scale on the unemployment rate reduced the response.

unemployment into computable general equilibrium (CGE) models of environmental regulation.” The model allows for involuntary unemployment due to search frictions via a constant returns-to-scale matching function and the paying of above-market wages to retain workers. With regard to search frictions, unemployed workers can search for jobs in both sectors. The rate at which firms hire workers is a function of the ratio of aggregate recruiting effort in that sector to the number of unemployed workers. The higher the recruiting effort and the larger the number of workers searching for a job within a particular sector, the higher the probability of a match. A Nash bargaining process where workers are compensated at a rate equal to the opportunity cost of not searching for another job is incorporated into the model. The easier it is for a worker to find another job, the higher the compensation to induce them to stay. However, higher recruiting efforts in one sector reduces the probability of a match in the other sector – and those workers’ bargaining power - due to competition for workers. They found that, on net, employment effects of an emissions tax were small; while employment fell in the polluting sector, this was offset by an employment gain in the non-polluting sector. Hafstead and Williams (2016) also explored several extensions of the model: one in which wages cannot be renegotiated in every period, which introduces short-run frictions that slow the rate at which wages can adjust to the long run rate, and one in which the productivity of firms is asymmetric across sectors.

#### *5.1.5 Modeling of labor markets using other economy-wide approaches*

In considering the employment effects of regulations, Smith (2012) suggested that “we need to start with first principles and consider how large-scale policies should be evaluated within models that allow for unemployment as a structural feature of the economic system.” Given that most CGE models are long-run full employment models without explicitly modeling of labor market interactions, Smith’s observation leads to the question of whether other types of economy-wide models have attributes or features that more naturally accommodate unemployment in the short and/or long run.

In this section, we briefly discuss two classes of models that have been used in the academic literature to examine the impacts of larger-scale policies on labor markets: I-O macro-econometric models and dynamic stochastic general equilibrium (DSGE) models. Since these types of models are used relatively rarely to examine the labor market impacts of environmental regulation, we also briefly dip our toe into a broader literature that uses these models to evaluate environmental tax reform and monetary policy. The summary herein reflects only an initial foray into the area with the intent of informing SAB discussion in order to assess whether further investigation into the potential application of these types of economy-wide modeling frameworks for analysis of air regulations seems a particularly fruitful avenue for EPA to pursue in the future.

#### *Labor markets and I-O macro-econometric models*

While CGE models assume full market clearing, I-O macro-econometric models assume imperfect knowledge of product and factor markets, with an emphasis on tracking short run disequilibrium – such as business cycles or cyclical unemployment - over time (West, 1995; EPA, 2010a).<sup>39</sup> While not explicitly

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<sup>39</sup> I-O macro-econometric models are often used to estimate the effects of monetary or fiscal policies, by measuring GDP and its components, while incorporating business cycle dynamics.

derived from microeconomic theory, I-O macro-econometric models are designed to be consistent with it: the short-run structure is commonly based in Keynesian theory such that variable outcomes are demand determined. In the long run, I-O macro-econometric models are consistent with neoclassical growth theory in that supply side effects dominate model outcomes (Arora, 2013). For instance, after a policy shock is introduced, the economy may depart from its long-term GDP growth path and the steady-state rate of unemployment, but eventually it returns to this path/rate (IeC and IERF, 2015). Generally speaking, the equations that represent the labor market in a national level I-O macro-econometric model have been described as relating changes in wages to the unemployment rate, indexed to consumer prices (OECD, 2004; Guivarch, et al. 2011). In some cases, the equation may also include a labor productivity effect (OECD 2004).

In the published academic literature, I-O macro-econometric models have been used to examine the effects of environmental policies on employment. Recent examples include Barker, et al. (2007) and Lehr, et al. (2012). Barker et al. (2007) found almost no effect of energy efficiency policies on employment in the United Kingdom. Lehr, et al. (2012) found positive net employment effects due to expansion of renewable energy in Germany under most scenarios, but results were sensitive to assumptions about growth in global markets, the ability to export renewable energy, and expectations regarding reductions in costs of renewable energy technologies in the future.

I-O macro-econometric models also have been used, particularly in Europe, to examine the employment effects of environmental tax reform, which taxes pollution and then uses the revenues to reduce distorting taxes elsewhere in the economy (for instance, on labor, income, or investment). Barker and Gardiner (1996) appear somewhat unique in that they modified a standard I-O macro-econometric model of Europe (i.e., E3ME) to more explicitly incorporate collective wage-bargaining between a union and firms at the sectoral level. Real wages in a sector were influenced by changes in sector-specific labor productivity, sector-specific employment, the aggregate wage rate in the economy, the income one receives when unemployed, and the unemployment rate.<sup>40</sup>

I-O macro-econometric models are premised on the assumption that historical relationships - as reflected in time series data - are valid predictors of future effects (European Commission, 2015). However, these models have also been criticized for lack of a micro-theoretic foundation and inability to reflect behavioral responses to out-of-sample shocks (i.e., the Lucas critique). In addition, lack of theoretical grounding combined with a large number of equations can make it difficult to disentangle what mechanisms are driving model results (U.S. EPA, 2010a). I-O macro-econometric models also have been criticized for inadequate supply-side specification (West, 1995), which may be of particular importance when evaluating effects of an air regulation.

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<sup>40</sup> Bosquet (2000) summarized the results from 56 different studies, noting that macroeconomic models – he did not specify which of these has an underlying I-O framework - predict a positive or zero impact on employment less often than CGE models. Relying on an updated list of studies, Patuelli, et al. (2005) performed a statistical meta-analysis and found results consistent with Bosquet. However, while model type was statistically significant, it did not explain differences across studies in the effect of environmental tax reform on employment.

### *Labor markets in Dynamic Stochastic General Equilibrium (DSGE) models*

Like CGE models, DSGE models are grounded in microeconomic rational choice theory and include assumptions about preferences, technology, and budget constraints. Moreover, as in many CGE models each agent in the model is assumed to make an optimal choice, taking into account prices and the strategies of other agents, both in the current and future periods. A key distinction between CGE and DSGE models is that DSGE models are stochastic and more focused on how the economy adjusts to shocks over time (Arora, 2013). Specifically, they allow one to examine the implications of policy when there are random, exogenous shocks to the economy, some of which may interact with other important policy-relevant factors. The original impetus for developing DSGE models, as described in the literature, is as an alternative to large-scale macro-econometric forecasting models that had been criticized for their lack of theoretical underpinnings, ad hoc specification, and lack of independence from the policy regime. As such, they have been used to provide a theoretically grounded way to test various macroeconomic theories and study the cyclical effects of monetary and fiscal policy; their use in other areas appears to have also greatly expanded in the last decade (Rickman, 2010).

While DSGE models are often used by central banks and in academic research (Woodford, 2009; Sbordone, et al., 2010), they have not yet displaced other macro modeling techniques as the main “workhorse” model used to evaluate the future implications of different policy options (Rickman, 2010; JCT 2015).<sup>41</sup> For our purposes, it is interesting to note that until relatively recently most DSGE models have assumed long-run full employment (Galí, 2015).

In the environmental policy context, there appears to be relatively few applications that rely on a DSGE model. Thus far, DSGE models used in this context have typically been highly aggregate, stylized representations of the economy that assume long-run full employment. For instance, one set of papers compared how different economic instruments perform in an economy that faces some pre-defined set of exogenous productivity, price, or wage markup shocks (e.g., Fischer and Springborn, 2011; Heutel, 2012). Unlike Heutel (2012), Fischer and Springborn (2011) incorporated labor explicitly into their model. In a model with stochastic, transitory productivity shocks, they found no effect on labor supply under an intensity target. For an emissions cap or tax, labor supply responded pro-cyclically: it increased relative to the steady state, due to a larger response in investment relative to consumption, which then dampened the response of the marginal value of income relative to marginal productivity of labor (i.e., which move in opposite directions) in the short run. Another set of papers combined aspects of DSGE models with global integrated assessment models—Nordhaus’ DICE or RICE model, in particular - for the analysis of climate policy (e.g., Cai et al., 2012; Lemoine and Traeger, 2014; Barrage, 2014). While labor was sometimes explicitly modeled as an input to production, these papers did not discuss how exogenous shocks affect labor supply.

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<sup>41</sup> When analyzing major tax proposals in Congress the JCT uses a macroeconomic equilibrium growth model that allows for less than full employment in the short run and models labor supply separately for high income primary earners, high income secondary earners, low income primary earners, and low income secondary earners. The JCT also relies on overlapping generations and DSGE models that assume full employment. The models differ in the degree of foresight consumers have regarding future fiscal policy (JCT 2011). Recent analyses released by the JCT report results based on the first two types of models (JCT 2015).

New Keynesian DSGE models incorporate price-setting frictions as an explicit structural feature of a DSGE model, which then allows for the possibility that nominal rigidities interact with exogenous shocks in ways that produce persistent, real effects. Romer (2012) noted that the field still disagrees regarding the best approach for modeling incomplete price adjustment. He observed that the way in which this adjustment process is modeled – and therefore responds to a shock - can imply markedly different macroeconomic consequences.<sup>42</sup> That said, for tractability wage stickiness often has been incorporated into NK DSGE models via a time-dependent adjustment process consistent with the idea that wages are fixed when a contract is in place, but contract length is stochastic (i.e., a Calvo sticky-price approach) (Romer, 2012; Christiano, et al. 2011). Recent research has explored explicitly introducing unemployment into a NK DSGE model with or without wage stickiness. For instance, unemployment has been introduced by modeling labor supply as a stochastic process (e.g., Christiano, et al., 2011), allowing for involuntary unemployment due to search frictions (e.g., Galí, 2011), or incorporating market power in labor markets, which then introduces a wedge between the marginal worker’s reservation wage and the prevailing market wage (e.g., Galí, 2015). To our knowledge, NK DSGE models have not yet been utilized to evaluate the effects of environmental policies on employment.

## 5.2 Capital markets in CGE models

This section outlines the treatment of capital in CGE models with separate discussions of long run capital formation and the role of expectations; and the ability—or inability—of CGE models to represent short run impacts on capital through capital vintaging and adjustment costs. The treatment of capital markets in CGE models plays a central role in capturing the behavioral response of markets to regulation and the economic impacts that are implied by them.

### *5.2.1 Standard treatment of capital formation in CGE models*

The degree of foresight in a CGE model has important implications for the evolution of capital formation. Dynamic models in which investment is modeled over time are classified as either recursive dynamic or forward-looking dynamic. In recursive models agents and firms make optimal production, consumption, and investment decisions with information for only a single period and ignore future changes in prices and technologies. In contrast, agents and firms in forward-looking models optimize these decisions over time. Economic agents operate with perfect expectations about the evolution of prices and technologies. Consumers are able to look forward and choose levels of consumption and savings that maximize utility over time.

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<sup>42</sup> For instance, a time-dependent adjustment process introduces nominal rigidities via multi-period contracts that set prices and/or wages where some fraction of contracts expire over time and must be renewed, at which time prices can be renegotiated. Assumptions vary with regard to whether prices/wages are fixed or fluctuate in some predetermined fashion when the contract is in place, as well as whether contract length is deterministic or random (the Calvo sticky-price approach is one such variant). Another approach is to model a state-dependent adjustment process where prices and/or wages do not adjust instantaneously due to a constant fixed cost. Other approaches allow prices to adjust when they are explicitly reviewed by firms. See Romer (2012).

In both recursive dynamic and forward looking models the formation of capital,  $K_{t+1}$ , is a function of the previous period's investment  $J_t$  plus the fraction of undepreciated capital remaining from the previous period,  $K_t$ , where  $\delta$  is the geometric depreciation rate:

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

However, in a recursive dynamic formulation the level of investment  $J$  may be based on a fixed fraction of income in each period (see e.g. Robinson and Lofgren, 2005), endogenously determined by substituting for current period consumption (see e.g. Paltsev et al., 2005) or estimated as a function of expected returns (see e.g., Dixon and Rimmer, 2001). In a forward-looking model the pathway of consumption, savings, and investment is optimized over time.<sup>43</sup>

Table 7 summarizes several key characteristics of capital markets from seven U.S. CGE models. Five of these U.S. CGE models are described as forward-looking models (i.e., ADAGE, EMPAX-CGE, IGEM, US-REGEN, and NewERA) and two are dynamic recursive models (i.e., US REP, USAGE). See the social cost white paper for a discussion of how the degree of foresight assumed in a model affects predictions of overall economic welfare.

**Table 7: Characteristics of capital markets in CGE models of the U.S.**

MODEL	DEVELOPER	CHARACTERISTICS OF CAPITAL MARKETS		
		FORWARD LOOKING	VINTAGING	ADJUSTMENT COSTS
<b>ADAGE-US</b>	RTI	Yes	No	Quadratic
<b>EMPAX</b>	RTI	Yes	No	Quadratic
<b>IGEM</b>	DJA	Yes	No	No
<b>US REP</b>	MIT	No	Yes	Technology-specific constraints
<b>US-REGEN</b>	EPRI	Yes	No	Technology-specific constraints
<b>NEWERA</b>	NERA	Yes	Yes	Technology-specific constraints
<b>USAGE-ITC</b>	CoPS	No	No	Adaptive Expectations

Note: Compiled from available documentation, which is more complete for some models than others.

While we did not find published literature that analyzes how the degree of foresight in a U.S. CGE model affects capital formation, Babiker et al. (2009) compared the forward-looking and recursive dynamic versions of the MIT EPPA model. They noted that there are tradeoffs between the two frameworks. The forward looking version allows economic actors to respond to future expectations of prices, output

<sup>43</sup> It is worth noting that most of the discussion in the literature on capital formation refers to physical capital or the flow of capital across regions. Few models, one being G-Cubed (McKibbin and Wilcoxon, 2013), dynamically represent exchange rates and financial arbitrage.

levels, and policy. This is particularly useful for policies that employ banking and borrowing. However, simplifications must be made to the forward-version in order to obtain a feasible solution. In particular, the full treatment of vintaging and short-run adjustment costs are dropped and the number of low-emission technologies is reduced.

### 5.2.2 Capital vintaging and malleability

There are two main approaches to modeling the capital stock in dynamic CGE models, often referred to as “putty-putty” and “putty-clay” (Phelps, 1963). Models that use the “putty-putty” approach assume an undifferentiated capital stock that is fully malleable and moves instantaneously (and therefore costlessly) between sectors of the economy. In contrast, models that use a “putty-clay” approach differentiate between new investment, which is fully malleable across sectors (i.e., putty), and existing capital, which is sector-specific and has fixed input shares (i.e., clay).

Broadly speaking, older vintages of capital also tend to produce more pollution per unit of output and are less efficient.<sup>44</sup> The representation of vintaging affects how firms respond to regulation. In models with vintaging, a regulation where new equipment is needed to meet emission requirements will result in transition costs as outdated technology is retired and replaced or as capital is moved across sectors (Pizer and Kopp, 2005). In contrast, model without vintaging may costlessly reallocate capital and adjust to new factor prices. The inclusion of vintaging also slows investment in new technologies because they must compete with existing technologies for which there is no alternative use (McFarland et al., 2004).

Models vary widely in the treatment of vintaging. Among the seven U.S. CGE models summarized in Table 7, only two incorporate capital vintaging. NewERA, a forward-looking model, has two classes of capital: new investment (fully malleable) and a single vintaged stock for each sector. US REP, a dynamic-recursive model, has 12 vintages of capital for each sector. Other models, such as IGEM and EMPAX, have fully malleable capital stock. In practice, for models without explicit representation of vintaging, the elasticities of substitution on inputs to a technology may be lowered to partially capture the effects of vintaging. It is unclear how closely such changes mimic explicit treatment of vintaged capital.

For a model with a vintage capital structure, the capital stock is a function of new investment, the depreciated fraction of capital that remains malleable, and the depreciated fraction of capital that becomes rigid where  $\theta$  is the fraction of newly installed malleable capital that becomes non-malleable in the next period and  $v$  is the capital vintage (e.g., Jacoby and Sue Wing, 1999 and McFarland et al. 2004).

$$K_{t+1} = J_t + (1 - \theta)(1 - \delta)K_t + \theta \sum_v (1 - \delta)^v K_{t+1-v}$$

In a more recent permutation of the treatment of vintaged capital (Chen et al. 2015), only the last vintage of the non-malleable capital depreciates and at that point it depreciates fully. The revised

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<sup>44</sup> Exogenous reductions in the energy-intensity of new capital are modeled using autonomous energy efficiency improvement (AEEI) parameters that capture empirically observed, non-price induced energy-saving technological change over time. Assumptions regarding technological change in CGE models are discussed in more detail in the social cost whitepaper.

approach is consistent with long-lived capital, such as power plants, that are unable to make significant input adjustments over their lifetime. This has the effect of extending the effective life of that capital and slowing the adoption of competing technologies.

### 5.2.3 Short-run adjustment costs

While capital vintaging focuses on existing capital, the representation of short-run adjustment costs emphasizes investments in new capital. A phenomenon seen at both macro and micro scales is that a rapid increase in the level of investment in new physical capital leads to higher input costs. This may be attributed to scarcity of specialized human resources (e.g., skilled labor such as engineering services, pipefitters, and welders) or specialized physical capital (e.g., turbines, nuclear reactor cores). For example, within the EPPA model, short-run adjustment costs for new low-carbon emitting technologies are represented by requiring a small fraction of specialized resources that are fixed in the short-term and grow with increasing levels of investment (McFarland et al. 2004, Chen et al. 2015).

Of the seven U.S. CGE models in Table 7, EMPAX and USAGE both explicitly allow for adjustment costs associated with the installation of new capital. EMPAX represents short-run adjustments costs associated with the installation of new capital through a quadratic equation following Uzawa (1969).<sup>45</sup> In order to install  $J$  units of capital, a firm must purchase a slightly greater amount  $I$  that depends upon the ratio of new investment to existing capital ( $J/K$ ). The amount of additional capital, or the difference between  $I$  and  $J$  is the cost of installation services.

In the recursive dynamic USAGE-ITC model (Dixon and Rimmer, 2002) limits to the rates of investment are captured within the capital supply functions to represent caution on the part of investors (i.e., adaptive expectations). The USREP, US-REGEN, and NewERA models all employ technology-specific adjustment costs. In the case of US-REGEN and NewERA, which are linked to electric sector dispatch models, adjustment costs are incorporated by placing limits on the penetration rates of new technologies in the sector model.

## 5.3 Sectoral impacts

A key feature that may determine the ability of a model to capture the effects of an air regulation on economic activity is degree of sectoral aggregation. Many economy-wide models are highly aggregated and the regulated sector or sectors may not appear separately in a particular model. In addition, highly aggregated models may not include separate sectors for which secondary market impacts are of interest. However, in some cases, some of these effects can be captured through linking a CGE model with a more disaggregated partial equilibrium model (see the social cost white paper for a detailed discussion). While the main focus of this section is on the use of CGE models to evaluate sectoral impacts, we also briefly discuss other economy-wide modeling approaches that have been used to evaluate the sectoral effects of national regulation.

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<sup>45</sup> This approach is also found in the multi-country G-Cubed CGE model (McKibben and Wilcoxon, 2013).

### 5.3.1 Sectoral aggregation in CGE models

Table 8 shows the number of sectors and regions in seven CGE models that have been used to analyze U.S. environmental regulations and policies. The number of sectors varies greatly, from as few as nine to almost 500. Models used by EPA to analyze regulations – EMPAX and IGEM – both have 35 sectors.

The level of sectoral detail that can feasibly be included in a CGE model is determined by the availability of underlying data. In particular, the main source of sectoral data for a CGE model is an input-output table. The Bureau of Economic Analysis (BEA) compiles input-output tables for the U.S. Benchmark tables with the highest level of sectoral disaggregation are compiled for every fifth year. The most recent benchmark table, released in 2013, is for 2007.<sup>46</sup> The main 2007 benchmark table is compiled in 15-, 71-, and 389-industry aggregations. Non-benchmark tables, extrapolated at the 15- and 71-industry levels using national accounts data, are available yearly through 2014. IMPLAN also uses the BEA tables and supplementary data to produce commercially available input-output tables at the national, state, and county levels.<sup>47</sup> The most recent IMPLAN input-output tables have 536 sectors at their most disaggregated level. IMPLAN also augments the input-output data to create social accounting matrices (SAMs) which complete the circular flow of income and products through households and governments, including non-market transactions such as transfer payments.

**Table 8: CGE models used in analyses of U.S. environmental regulations**

Model	Developers	U.S. Regions	Sectors
ADAGE-US	RTI	5 to 9	10
EMPAX	RTI	5	35
IGEM	DJA	1	35
USREP	MIT	12	11
US-REGEN	EPRI	15	9
NewERA	NERA	11	12
USAGE-R51 <sup>48</sup>	CoPS	51	497

Note: Compiled from available model documentation. Some models use multiple aggregations.

Although input-output and social accounting matrix data may be available at a relatively high level of disaggregation, other data and parameters for the model may not. Econometrically estimated

<sup>46</sup> [http://www.bea.gov/industry/io\\_annual.htm](http://www.bea.gov/industry/io_annual.htm).

<sup>47</sup> IMPLAN (IMPact analysis for PLANning) data and software was originally developed for the USDA's Forest Service for use in creating multi-year management plans. See <http://www.implan.com>.

<sup>48</sup> USAGE-R51 is a state-level variant of the USAGE-ITC model (single region national model).

parameters for demand systems, production functions, and foreign trade are not generally available at high levels of disaggregation.

A number of researchers have attempted to determine the effects of aggregation on both sectoral and economy-wide simulation results. In the context of the potential for border measures as a component of climate change agreements, Alexeeva-Talebi et al. (2012) and Caron (2012) utilized data and models that allowed comparisons between impacts on several industrial sectors and their disaggregated subsectors. Not surprisingly, they found that the range and standard deviation of sectoral impacts increased with disaggregation. In some cases the direction of the estimated impacts was reversed. Greater disaggregation allows for better matching of Armington elasticities, and it was shown that sectoral results can be quite sensitive to these values. While sectoral estimates are quite sensitive to the level of aggregation, Alexeeva-Talebi et al. (2012) and Caron's (2012) economy-wide estimates for variables such as carbon prices and leakage rates appear to be less so. Thus, while a highly aggregated model may not be a reliable predictor of sub-sectoral impacts, for many applications these models may be capable of making satisfactory estimates of impacts on economy wide variables.

As previously noted, a CGE model is able to identify interactions and indirect economic impacts that ripple through sectors of the economy beyond those directly affected by a regulation. Such effects could potentially be significant for relatively large regulatory shocks and therefore of interest to policymakers and the public. For example, Hazilla and Kopp (1990) examined the impact of Clean Air and Clean Water Act compliance costs on the U.S. economy and estimated that for the finance, real estate, and insurance sector, which bore no direct compliance costs, output would fall by almost 5 percent (and employment by almost 2.5 percent) in 1990. In contrast, EPA (2011c) found that effects of Clean Air Act Amendment compliance costs on output in indirectly affected sectors in 2020 were expected to be quite small (typically less than 1 percent). Neither of these cases considered the effects of benefits on sectoral impacts, however. When health improvements were incorporated into the CGE model via labor force participation (households allocated relatively more of their time to leisure) and medical expenditure effects (households incur fewer expenditures and therefore have more income), EPA (2011c) found that indirectly affected but more labor-intensive industries such as services (aside from health) experienced a small increase in output due to the greater availability of labor.

### *5.3.2 Alternative market structures in CGE models*

Most CGE models assume perfect competition and constant returns to scale, including the seven U.S. CGE models described in Table 8. In these models there is no scope for explicit entry and exit of firms as market conditions change. However, a number of CGE models have been constructed that include oligopolistic or monopolistically competitive sectors. Francois et al. (2013) provide a survey and exposition on how these alternative market structures have been incorporated into CGE models.

The impetus to incorporate representations of imperfect competition into CGE models began in the 1980s following the advent of the "new" trade theory. Harris (1984), for example, developed a CGE model of the Canadian economy with scale economies and imperfect competition and showed that

incorporation of these features produced much larger gains from trade liberalization than was the case with constant returns to scale and perfect competition. More recently, monopolistic competition has underpinned models with Krugman and Melitz specifications that have been proposed as alternatives to the Armington specification assumed in most CGE models (Balistreri and Rutherford, 2013; Dixon et al., 2015). CGE models with these specifications have also produced much larger gains from trade than their counterparts with the Armington specification and perfect competition.

To date, most applications of imperfect competition in CGE models have been in international trade; environmental applications have been limited. One exception is Babiker (2005), who constructed a multi-country CGE model with an oligopolistic structure and increasing returns to scale in the energy-intensive goods sector. He found that shifts in output between regions and emissions leakage were larger with the oligopolistic market structure. These shifts were even greater when the Armington specification for trade was replaced with a Heckscher-Ohlin assumption of homogenous products.

While the use of alternative market structures in CGE models has been shown to have strong effects on outcomes, most existing applications have been quite stylized. Sectors in CGE models are often aggregates of multiple subsectors and it may be difficult to ascribe an appropriate alternative market structure that fits the entire sector. This, and lack of data on appropriate parameters, present significant challenges for including alternative market structures in economy-wide analyses (see the accompanying competitiveness memo for more discussion).

### *5.3.3 Limitations of CGE models for sectoral analysis and possible solutions*

As discussed above, due to data limitations and/or modeling focus, many CGE models do not have high levels of sectoral disaggregation. This presents an inherent limitation on the ability of these models to analyze some sectoral impacts. For example, few CGE models can capture substitution possibilities between very specific subsectors such as cement and asphalt or include different production processes for goods such as steel. In many cases, a CGE model may not be an appropriate tool for capturing the sectoral effects of regulation.

In cases where it is desirable to have the economy wide focus of a CGE model and some additional sectoral detail, there are several possible approaches. One possibility is to link a CGE model with a detailed dispatch or PE model that captures sub-sectoral substitution possibilities while the CGE model estimates the economy-wide impacts. Grant et al. (2007) did this to examine potential impacts in the U.S. dairy industry resulting from trade liberalization and Narayanan et al. (2010) employed a similar approach for the automotive industry in India. This is a relatively common technique for considering detailed impacts in the energy sector as well (e.g., Lanz and Rausch, 2011; Rausch and Mowers, 2014). Three of the U.S. CGE models (US REP, US-REGEN, and NewERA) are linked CGE-electricity sector models based on the work of Böhringer and Rutherford (2009). Another possible approach is to separate subsectors of special interest in the CGE model using sectoral data. For example, Duscha et al. (2015)

disaggregated the GTAP steel sector into the two primary production processes in their assessment of the potential for sectoral CO<sub>2</sub> emissions targets as part of a future climate agreement.<sup>49</sup>

#### *5.3.4 Sectoral impacts of national policies using other economy-wide approaches*

We found a few examples where sectoral impacts of national regulation have been analyzed in the academic literature using an input-output (I-O) approach. Some observe that because input-output models are capable of a high level of sectoral disaggregation, when used in the appropriate context they may provide “considerable insight into short term supply chain issues and how industries are related” (European Commission, 2015). However, while fixed prices may be a valid assumption when evaluating a policy in a local or regional context (West, 1995), this assumption may be less defensible in a national setting (e.g., when regulation is expected to affect sectoral supply and/or prices). The lack of resource constraints also means that I-O models frequently overestimate the economic effects of a policy. While the degree of overestimation is likely not too large when assessing local impacts, it may be of significant magnitude when analyzing the national economy (Dwyer et al., 2005; Dwyer et al., 2006; West, 1995).<sup>50</sup>

Ho, et al. (2008) and Adkins, et al. (2012) extended the traditional I-O approach to analyze the potential impacts of climate policies on U.S. industries. Their modeling methodology proxied for four time frames: the very short run, short run, medium run, and long run. In the very short-run, analyzed using an I-O model, output prices were fixed and increases in the prices of fossil fuel inputs had the maximum impact on industry profits. In the short-run, output prices and sales in the I-O model were allowed to adjust based on demand elasticities estimated with a multi-country CGE model. The medium-run analysis was performed using the CGE model alone, but with sectoral capital stocks fixed. In the long-run – a full general equilibrium analysis – all inputs and prices were allowed to adjust.

### 5.4 Impacts of energy prices

Regulations are often imposed on energy markets or products and equipment that use energy because fossil-fuel combustion is a significant source of air emissions. Air regulations are also imposed on non-fossil fuel energy sources, such as the combustion of biomass and emissions from nuclear facilities. As such, they can directly affect the use and production of energy (e.g., emission standards for power

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<sup>49</sup> The SplitCom utility can be used to divide GTAP sectors into component subsectors using available external information (<https://www.gtap.agecon.purdue.edu/resources/splitcom.asp>).

<sup>50</sup> Adkins, et al. (2012) characterized results from an I-O model as “hypothetical,” “very short run” and “the worst case scenario of the maximum damages that an affected industry might claim.” Dwyer et al. (2006) stated that the use of I-O analysis for estimating impacts across the national economy introduced “a systematic and serious upward bias” due to its focus on the positive impacts on economic activity (e.g., an injection of additional revenues and an increase in demand for particular goods and services as well as labor) while ignoring “equally real negative impacts” (e.g., economic activity and workers drawn away from other markets). The OECD advised that results from I-O models be interpreted with “great caution” (OECD, 2004). IPI (2015) stated that I-O models are “best suited to estimating regional impacts and have limited applications to policies with large, widespread effects.”

plants), the quality of energy products (e.g., regulation of the sulfur content of gasoline), and the extraction of primary factors (e.g., emission standards that apply to oil and gas production).

Energy price impacts of regulation are often of interest to policy makers because the short and long run elasticities of demand for energy goods and inputs are often inelastic, energy goods are widely consumed and used as factors of production, and household demand for them is income-inelastic. More narrowly-defined regional or consumer class energy price impacts may also be of interest. This section discusses how an air regulation might be expected to manifest as a change in energy prices (5.4.1), how CGE models typically characterize energy markets, including potentially through linkages to other models (5.4.2), regional, supply chain, and customer class considerations (5.4.3), and recent methodological work on representing fossil fuel supply in economy-wide models (5.4.4).

#### *5.4.1 Effect of air regulations on energy prices*

There is a long-recognized relationship between energy markets and the overall economy (Hogan and Manne, 1977). In the U.S., primary energy markets comprise a relatively small share of the overall economy. However, regulations that affect the energy sector, and therefore energy prices, may have an outsized effect on the economy. Generally it is the elasticity of substitution between energy and other factors of production (as well as consumption) that determines the degree to which energy markets affect the economy. The lower the elasticity of substitution, the greater the impact of energy sector regulations on the economy, and the greater the potential for feedbacks back into energy markets.<sup>51</sup>

However, in practice the elasticity of substitution is not the only relevant parameter, in part because any particular air regulation is not imposed directly on all sources of energy, and therefore, to the extent that general equilibrium effects of such a regulation may be important, the ability of producers and consumers to substitute across sources of energy is relevant to estimating price and welfare impacts. Furthermore, often new air regulations are adopted or tightened coincidentally with new information on abatement or production technologies, suggesting that the elasticity of substitution may not be as important of a factor or has meaningfully changed such that historic data are unreliable.

While potentially complex to model, the expected effects of air regulations on energy markets are not conceptually unique: we expect a regulation to affect the use of goods and services used in the directly regulated sectors, and to shift intermediate and final demand away from those sectors. However, because energy goods are important inputs into the production of so many different goods and services, regulation of emissions from energy production could affect many other sectors of the economy. For example, when the price of an energy commodity increases, one would expect decreases in production and increases in market prices in sectors for which that commodity is an input, *ceteris paribus*. Smaller changes in energy price changes are expected to lead to smaller impacts within markets that use these inputs. However, a number of factors influence the magnitude of the impact from energy price changes on production and prices in sectors that use energy in production.

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<sup>51</sup> Another implication of this result is that the importance of capturing general equilibrium impacts of a regulation relative to a PE approach may depend on the elasticity of substitution.

*Share of Total Production Costs:* The impact of energy price changes in a particular sector depends, in part, on the share of total production costs attributable to those commodities. For sectors in which energy commodities are only a small portion of production costs, the impact will generally be smaller than for sectors in which these inputs make up a greater proportion of total production costs. Therefore, more energy-intensive sectors would potentially experience greater cost increases when energy prices increase, but would also experience greater reduced costs when these input prices decrease.

*Ability to Substitute among Inputs:* The ease with which producers are able to substitute other inputs for energy commodities and among energy commodities, influences the impact of their price changes. Those sectors with a greater ability to substitute across energy inputs or to other inputs will be able to, at least partially, offset the increased cost of these inputs resulting in smaller market impacts. Similarly, when prices for energy commodities decrease, some sectors may choose to use more of these inputs in place of other more costly substitutes.

*Availability of Substitute Goods and Services:* The ability of producers in sectors experiencing increases in input prices to pass along the increased costs to their own customers in the form of higher prices depends, in part, on the availability of substitutes for those goods and services (either other domestic products or foreign imports). If close substitutes exist, the demand for the product will in general be more elastic and producers will be less able to pass on the added cost through a price increase.

While the above discussion focuses on how producers may respond to changes in energy prices, similar influences determine the effect of changes in energy prices on household behavior. They may respond to changes in energy prices by purchasing goods that use energy more or less intensely (i.e., energy efficiency), spending more or less effort conserving energy (e.g., turning off lights, planning combined trips), and/or substituting across activities with different levels of energy intensity. Similarly, as the price of products that use energy change, households may alter their consumption behavior. However, it is important to note that households may vary in the degree to which they can shift consumption of energy in the short and long run. Income effects influence the response of households to changes in energy prices. See section 5.5 for a discussion of how CGE models have been utilized to estimate the economic impacts of environmental regulation on households on the basis of income.

#### *5.4.2 Standard treatment of energy markets in CGE models*

As previously noted in the social cost white paper, CGE models typically have highly aggregate representations of the energy sector, with continuous, separable nested constant-elasticity of substitution (CES) production functions. Calibration exercises require specifying elasticity of substitution parameters, but empirical estimates are rare at the level of aggregation required in a CGE model. In addition, CGE models often reflect very different priors about how technological change and substitution possibilities occur than is assumed in detailed partial equilibrium energy sector models.

At a minimum, most CGE models represent energy markets for the three primary fossil fuels—oil, natural gas, and coal—and intermediate forms such as electricity and refined petroleum products. Table 9 shows the energy sector detail in seven U.S. CGE models. The electric power sector contains the most

detail: many models represent eight or more individual technologies either directly within the CGE model or in an electricity sector model that is then linked to the CGE model. Some models also represent other primary forms of energy such as biomass, shale oil and coal gasification.

**Table 9: Level of energy-sector detail in U.S. CGE models**

<b>Model</b>	<b>Energy Sub-Sectors</b>
ADAGE	4 non-electricity (crude oil production, natural gas production, coal production, petroleum refining); 9 to 36 fossil electricity generation technologies (36 via linked model)
EMPAX (dynamic)	4 non-electricity (crude oil production, natural gas production, coal production, petroleum refining); 2 electricity generation technologies (fossil, non-fossil)
IGEM	4 non-electricity (oil and gas extraction, coal mining, natural gas distribution, petroleum and coal products manufacturing); 1 electricity generation technology (generation, transmission, distribution)
US REP	7 non-electricity (crude oil production, natural gas production, coal production, petroleum refining, coal gasification, shale oil, biofuels); 11 to 20 electricity generation technologies (20 via linked model)
US-REGEN	4 non-electricity (crude oil production, natural gas production, coal production, petroleum refining); 30 electricity generation technologies (30 via linked model)
NewERA	5 non-electricity (crude oil production, natural gas production, coal production, petroleum refining, biofuels); 20 electricity generation technologies (20 via linked model)
USAGE-R51	6 non-electricity (oil and gas extraction, coal mining, oil transmission, natural gas transmission, natural gas distribution, petroleum and coal products manufacturing); 8 electricity generation technologies

The net effect of regulation on energy markets is a product of the interactions of both supply and demand responses in the medium- to long-run.<sup>52</sup> The supply-side of these markets is discussed first. The typical fossil fuel production function relies upon a constant elasticity of substitution production function that allows for substitution between a fixed-factor fossil fuel resource and another nest comprised of value-added and/or other intermediate inputs. Typical values for the fossil fuel supply elasticity are shown in Table 10. The standard specification also accounts for depletion of the fixed factor resource over time. The production function for these fuels may include components of their delivery networks (e.g. fuel pipelines).

<sup>52</sup> In addition to the model features summarized here, an important element of the representation of energy markets in CGE models is the rate of technological improvement in the energy-intensity of new capital. See the social cost whitepaper for a discussion of technological change in CGE models.

**Table 10: Elasticity of supply for fossil fuel resources**

MODEL	OIL	GAS	COAL
<b>ADAGE</b>	1.2	1.8	5.4
<b>EMPAX</b>	1.2	1.8	5.4
<b>IGEM</b>	Not available	Not available	Not available
<b>US REP</b>	1.2	1.8	5.4
<b>US-REGEN</b>	User specified	User specified	User specified
<b>NEWERA<sup>53</sup></b>	0.3 in 2013 1.0 in 2038	0.3 in 2013 0.7 in 2038	0.4 in 2010 1.5 in 2038
<b>USAGE-ITC</b>	Not available	Not available	Not available

Note: Compiled from available model documentation.<sup>54</sup>

EMPAX, ADAGE, and US-REP all rely on methodology and data from Paltsev et al. (2005), which derives a long-run constant elasticity of supply curve through several resource grades. NewERA relies on econometric estimates of supply elasticities in early periods and grows those values over time to represent technical change. The standard specification also accounts for depletion of the fixed factor resource over time. Some models, such as NewERA and ADAGE, often take an additional step to calibrate fossil fuel price paths to approximate those of the U.S. EIA’s Annual Energy Outlook by solving for the underlying factor resource path. Barring exogenous assumptions that improve productivity over time, fossil fuel prices rise over time due to depletion and rising demand.<sup>55</sup> Intermediate energy markets such as refined oil and electric power are often treated as intermediate industries in nested production functions with inputs of primary energy, capital, labor, and other goods and services.

Note that elasticity of supply estimates are not available for IGEM, an econometrically estimated model with nested translog production functions. Supply elasticities are essentially infinite for coal because the model does not contain a resource endowment and coal is produced with a constant returns to scale technology. The oil and gas extraction sector in IGEM approximates a fixed factor resources by holding capital in the sector constant over time. However, an elasticity of supply parameter is not reported because elasticities in IGEM are calculated endogenously.

On the demand side, energy is an input into intermediate production and final household consumption. The ability of producers and consumers to respond to changes in input prices influence how changes in energy prices ripple through the economy. A greater ability to substitute across types of energy inputs and between energy and value added inputs dampens the effect of energy price changes on

<sup>53</sup> In NewERA only metallurgical coal, roughly 10% of the market, is modeled in this manner. Coal supply for the electric power sector is modeled through regional supply curves in a linked, bottom-up power sector model.

<sup>54</sup> The fuel supply elasticities,  $\eta_f$ , for EMPAX and US-REP are estimated as a function of the elasticity of substitution between the fixed factor resource  $\sigma_{fr}$  and the fraction of the fixed resource in the base-year production  $\alpha_{fr}$  through the following equation:  $\eta_f = \sigma_{fr} (1 - \alpha_{fr}) / \alpha_{fr}$  (see Babiker et al., 2001).

<sup>55</sup> In multi-country models, markets for crude oil are commonly treated as a Heckscher-Ohlin good with a single price while natural gas and coal are treated as Armington goods.

intermediate production and final consumption. Table 11 shows the values of important elasticities of substitution in intermediate non-energy production and final consumption including inter-fuel substitution and between the energy–value added bundle.

**Table 11: Energy-related elasticities of substitution in production and consumption**

MODEL	INTERMEDIATE NON-ENERGY PRODUCTION			HOUSEHOLD CONSUMPTION	
	Energy and K or KL bundle	Fossil Interfuel Substitution	Electric and Non-electric	Interfuel Substitution	Energy and Non-energy
ADAGE	0.5	1.0	0.5	0.4	0.25
EMPAX	0.5	1.0	0.5	0.4	0.25
IGEM	2.0	0.4 – 0.9	0.5 – 1.0	0.7	0.39
US REP	0.4 - 0.5	1.0	0.5	0.4	0.25
NEWERA	0.1 – 0.5	0.1 – 0.5	0.1 – 0.15	0.1 – 0.5	0.1 – 0.5
USAGE-ITC	Not available	Not available	Not available	Not available	Not available

Note: Compiled from available model documentation or directly from developers in the case of IGEM. IGEM parameters represent value-weighted averages across non-energy sectors. USAGE parameters were not reported in the literature.

With the possible exception of linked models, CGE models typically represent medium- to long-run energy prices (i.e., 2-5 and 5-10 years respectively), as opposed to short-run prices (i.e., months to a year) (Bernstein and Griffin, 2005; Beckman et al, 2011). Most CGE models are calibrated with medium- to long-run elasticity parameters to be consistent with model time steps of two to five years.<sup>56</sup> There is no standard temporal definition for short-, medium-, and long-run energy prices. Over the short-run, producers and consumers have limited ability to substitute among factor inputs or make new investments in response to changes in energy prices. For example, an increase in residential electricity prices may lead to behavioral responses in the short-run (e.g., turning off lights and changing thermostat set points). Over the long-run the price increase may spur investments in more efficient lighting and cooling systems.

Other regulatory and technical details that are not represented in CGE models may affect the impacts of air regulations on energy prices. Energy markets are often subject to economic regulation unique to these markets. For example, electricity generation is often subject to cost-of-service pricing, which influences the composition of the capital stock and equilibrium investment in those markets in a way that differs from an assumption of perfect competition (e.g. Parry, 2005; Burtraw, et al., 2001). Retail natural gas pricing structures often do not represent variable and fixed production costs that lead to

<sup>56</sup> Although some CGE models have an annual time step, the underlying elasticity parameters are still based on medium- to long-run estimates (see e.g., Jorgenson et al., 2013).

inefficiency (e.g. Davis and Muehlegger, 2010). Similarly, numerous tax policies and production requirements that favor particular production technologies are often not represented in CGE models.<sup>57</sup>

Furthermore, there are often aspects of delivery networks, new production technologies, and emissions abatement methods that affect the way that energy may be used and emissions controlled that may not (yet) be represented in a CGE model. These regulatory and technology details are often, though not always, represented in technology-rich sector models. Thus, linking detailed energy market models to CGE models may secure the advantages of each modeling approach to provide useful information on the potential energy market impacts of a regulation. For example, system constraints in transporting energy, particularly electricity and natural gas, may lead to short-run price increases because the lowest cost sources of production cannot easily access the market. Fluctuations in weather patterns at daily, monthly, and seasonal scales also alter the demand for and short-run prices of heating and cooling services. Few CGE models are able to incorporate the effects of weather on energy demand and supply beyond changes in annual averages. However, linked versions of US REGEN (EPRI, 2015) and US REP (Rausch and Karplus, 2014) are capable of representing changes in sub-annual electricity demand. That said, even CGE frameworks that are linked with technology-rich energy market models may omit factors that influence price formation such as the presence of futures markets.

Of the seven U.S. CGE models described in Tables 9, 10, and 11, three have been explicitly linked to detailed models of the energy or electricity sector in order to integrate the richness of a detailed sector model with the general equilibrium properties of a CGE model. (See the social cost white paper for details on how this linking was accomplished.) Sue Wing (2006), Lanz and Rausch (2011), and Rausch and Karplus (2014), examined the sensitivity of energy price impacts results to the level of detail and treatment of sector-specific technology requirements in a linked CGE-energy sector model context. Sue Wing (2006) compared the results of a hybrid CGE model with a detailed representation of generating technologies in the electricity sector with an otherwise comparable model lacking this detail. He found that the two models yielded comparable projections of energy commodity price changes for different levels of a carbon tax despite the hybrid model forecasting an increase in the use of natural gas and oil in the electricity sector, while the top down model forecast decreases in their use. The hybrid model also estimated higher impacts on electricity prices than the CGE model. In addition to differences in the number of production technologies represented in the two models, these differences were attributable to differences in the ability to substitute away from energy commodities for electricity production.

Lanz and Rausch (2011) compared simulations of a linked CGE-energy sector model to each of its stand-alone components. Compared to the linked model, they found that the stand-alone electricity sector model overestimated electricity price increases but underestimated reductions in electricity demand and sector emissions for the same CO<sub>2</sub> tax. This results from the inability of the partial equilibrium model to capture changes in the slope and position of the electricity demand schedule. This is true even when the PE demand curve is calibrated to the CGE model. Rausch and Karplus (2014) compared a clean

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<sup>57</sup> Pizer et al. (2006) finds that pre-existing taxes in the industrial, household transportation and commercial industrial sectors lead to important differences in marginal welfare costs of a carbon tax using models of these sectors versus a CGE model. This result is discussed in Section 4.5 of the social cost white paper.

energy standard and a renewable portfolio standard for the electricity sector using two versions of USREP, one with the native top-down electricity sector representation of USREP, and one that was linked to the ReEDS electricity sector model. USREP exhibited higher electricity price impacts than USREP-ReEDS for both policies in 2030 but estimated lower electricity price impacts in 2050.

#### 5.4.3 Regional, supply chain, and customer class considerations

Energy prices may vary widely by U.S. region, segment of the supply chain, and customer class. Regional energy price differences speak to the importance of capturing regional heterogeneity. Price differences across segments of the value chain and customer classes suggest that specificity is needed when describing absolute or relative energy price changes. The variation in state-level energy prices for 2013 is illustrated in Table 12.

**Table 12: Average, maximum and minimum energy prices across contiguous 48 states in 2013 for all customer classes (U.S. EIA, 2015)**

	Gasoline (\$/gallon)	Natural Gas (\$/mmBtu)	Coal (\$/mmBtu)	Retail Electricity (cents/kWh)
Average	3.45	6.44	2.52	10.1
Min	3.21	4.17	1.44	7.15
Max	3.74	10.53	4.87	15.7

Note: Average prices are weighted by consumption and expenditures across states and customer classes. Prices are in 2013 dollars and inclusive of consumption taxes.

Average gasoline prices show the smallest spread, though the annual average likely masks greater differences in the summer months. The highest natural gas, coal, and electricity end-use prices are found in the Northeast. The lowest end-use prices for natural gas and coal are found in the Gulf States and the Great Plains, respectively. Electricity prices vary across states depending on the composition of the generating fleet as well as differences in economic and other regulations.

Energy prices also differ across the supply chain and across customer classes. This is most apparent in the electric and natural gas sectors that require significant transmission and distribution infrastructure. As described in Table 13, both commodities show over a three-fold increase in residential prices above transmission hub prices.

**Table 13: Natural gas and electricity prices across the supply chain and customer classes for 2015 (U.S. EIA 2016a, b)**

<b>Natural gas</b>	Pipeline	City-Gate	Residential	Commercial	Industrial	Electric
\$/mmBtu	2.95	4.25	10.38	7.89	3.84	3.37
Index to pipeline		1.4	3.5	2.7	1.3	1.1

  

<b>Electricity</b>	Wholesale	Residential	Commercial	Industrial
Cents/kWh	3.5	12.7	10.6	6.9
Index to wholesale		3.6	3.0	2.0

#### *5.4.4 Recent literature on fossil fuel supply methods and parameters*

Two recent papers on the effectiveness of border carbon measures and leakage examined the importance of the methods and parameters related to fossil fuel supply, which will have follow-on effects on energy prices. Boeters and Bollen (2012) proposed an alternative specification to the fossil fuel production function typically used in CGE models. The authors noted that the typical formulation creates decreasing supply elasticities over time, which limits the responsiveness of energy supply. The proposed alternative specification has a constant elasticity of fuel supply, which allows for greater fossil fuel price adjustments. The different specifications did not alter leakage rates appreciably (though they altered the relative magnitude of leakage through fossil fuel price adjustments relative to leakage through embodied trade). Caron (2012), in a study of carbon leakage and the efficiency of border adjustments, compared the energy input substitution elasticities from GTAP and elasticities calibrated from the Department of Energy’s Manufacturing Energy Consumption Survey (MECS) data in a sensitivity analysis. The elasticities from MECS are reported to be smaller than those from GTAP. With these smaller elasticities, the carbon price required to achieve the same level of global reduction was over 20% higher. The author calls for further work on the estimation of energy input substitution elasticities.

### 5.5 Impacts on households by income class

This section discusses two main approaches used to evaluate the household distributional consequences of environmental policies in an economy-wide framework in the academic literature: linking the results of a CGE model to a separate household incidence model, and using a CGE model that explicitly integrates the behavior of different types of households into the model itself.

#### *5.5.1 Background*

Questions of how the costs and benefits of U.S. environmental policy are distributed across households have been explored in the economics literature since the 1970s (Parry et al. 2006). The use of computable general equilibrium (CGE) models to analyze distributional consequences is more recent; these studies mainly concentrate on analyzing the effects of market-based instruments such as environmental taxes or cap-and-trade policies; and almost exclusively focus on the distribution of costs. (This is not surprising given that most CGE models do not incorporate societal benefits; thus, when evaluating economic welfare they assume zero benefits from the policy. However, if there are benefits

then the economic welfare measure in CGE models is incomplete; it misses an important component of the welfare calculation.)

Often it is the firm that meets a new emissions standard or pays an environmental tax, so a key component of the analysis is mapping how those costs are borne by households, who supply labor, own capital, and purchase goods in the model. To accomplish this task, the analyst needs to account for the way markets – and in particular, households - respond. For example, a tax on the production of a good with relatively responsive demand (i.e., a flatter demand curve) will mostly be borne by producers – and therefore owners of capital - because any attempt to pass along the tax in the form of higher prices will result in consumers greatly reducing the amount of the good they purchase. If instead consumers are less responsive (i.e., demand is relatively steep compared to supply), the burden of the tax is shared between producers and consumers. The basket of goods consumed, what they represent as a proportion of income, and the ability to substitute away from one good to another likely varies with household income. Likewise, the main sources of income and the degree to which households respond to price changes by altering the factors of production they supply to the market may also vary with household income.

Studies that have examined the distribution of costs across households tend to find that environmental taxes or cap-and-trade policies are regressive absent consideration of how revenues are recycled (Parry et al., 2006; Pizer and Kopp, 2005): These policies tend to increase the price of energy-intensive goods, of which lower income households consume a higher fraction (e.g., Blonz et al., 2011; Rausch et al., 2010; Parry et al., 2006). Policy design parameters such as whether cap-and-trade allowances are auctioned or given away for free, or how revenues from the tax or auctioned allowances are used/potentially redistributed can substantially alter the expected regressivity of the policy (e.g., Burtraw and Parry, 2011; Rausch, et al., 2010). For instance, lump-sum transfer of collected revenues back to households can reduce the regressivity and sometimes even convert a cap-and-trade or tax into a progressive policy (e.g., West and Williams 2004). Most studies of the effects of carbon policies on household incidence use annual household expenditures as a measure of income. It has long been recognized that distributional consequences are likely to vary when wealth is used instead: For example, Dinan and Lim Rogers (2002) found that the difference in impacts across low and high income groups was less pronounced. Only a relatively small proportion of these studies utilized a CGE model.

The ability to drill down – particularly with respect to how different types of households are affected by a given policy – is limited in many CGE models of the U.S. economy due to the assumption of a representative household (i.e., the model has no ability to differentiate households on the basis of income or other socio-demographic characteristics that may be of interest to the policy maker). Some CGE models of the U.S. economy include more detailed representations of the household sector, though the degree of disaggregation varies by model, making it possible to evaluate the ultimate distribution of a tax after all prices and quantities have adjusted to accommodate the initial shock.

According to Bourguignon and Bussolo (2013), even CGE models with some heterogeneity in the household sector are often limited in their ability to fully evaluate the distributional implications of a

policy. These models typically evaluate the implications of aggregate price changes for household-specific consumption patterns and labor supply decisions but do not allow these behavioral changes to feedback into the model and, in turn, affect aggregate prices. The degree to which these feedbacks matter depends on the extent to which households respond differently to the policy (i.e., aggregation is described as imperfect in these cases: the top-down prediction only approximates the disaggregated response to the policy).

Bourguignon and Bussolo (2013) acknowledged that great strides have been made to integrate these two frameworks to simultaneously evaluate the general equilibrium and distributional implications of a policy. For instance, recursive linkages between the two models may allow for feedbacks between the aggregate prices predicted in the CGE model and highly disaggregated household behavioral changes in a micro simulation model. The ability to pursue a more integrated linkage between CGE and detailed micro models is limited, however, by the availability and quality of detailed micro data, and disconnects in the way income is defined at the household level versus aggregate level. Even more significant challenges remain in incorporating feedbacks between CGE and micro models that reflect household heterogeneity in a dynamic framework.

### *5.5.3 Linking representative household CGE model to separate household incidence model*

A number of papers have evaluated the distributional consequences of environmental policies by linking the results of a CGE model to a separate household incidence model. This is conceptually similar to a CGE model that distributes the shock to households differentiated by income but does not allow for these changes to feedback into the model. The first stage of the approach assumes or estimates price increases for consumer goods affected by the environmental policy. The second stage feeds estimated price increases into a household incidence model, often based on the Consumer Expenditure Survey, which includes demographic characteristics such as income as well as detailed information about consumption patterns.

Many studies in the literature that examine the distributional consequences of a carbon tax or cap-and-trade do not rely on a CGE approach for the first stage; instead they use I-O models to calculate the implied price increase of consumer goods based on their relative carbon content (Kopp and Pizer 2005). Note, however, that the estimated price changes from a CGE model may not be the same as those calculated using an I-O approach, since - unlike input-output tables - CGE models allow producers to modify production processes and a representative consumer to modify its consumption patterns in response to price changes. Metcalf (2007) used this approach when examining the distributional implications of a carbon tax (see Dinan and Lim Rogers (2002) for another example).

As previously discussed, U.S. EPA (2010c) adapted methodology from Burtraw et al. (2009) to evaluate the distributional implications of the proposed American Power Act across ten income classes in a near-term year. The incidence model was linked to a CGE model (ADAGE) via the change in electricity price,

while abatement costs in each sector in the incidence model were calibrated to the total abatement costs from CGE model.

Williams et al. (2014, 2015), and Gordon et al. (2015) paired a dynamic overlapping generations CGE model with a micro-simulation model of households to analyze the distributional implications of an unanticipated economy-wide carbon tax where the revenues are recycled either to labor, capital, or lump sum to households. As is the case with the papers described above, the CGE model results feed into a model that apportions the effects by income, generation, or region using highly detailed household level data from the Consumer Expenditure Survey; results from the household model are not fed back into the CGE model to capture behavioral changes in response to price. Williams et al. (2014, 2015) and Gordon et al. (2015) differ from U.S. EPA (2010c) and Burtraw et al. (2009) in two key respects. First, results were apportioned to households not only on the basis of consumption patterns but also sources of income (i.e., labor and capital). Second, they linked the two models based not only on price changes but also changes in consumer and producer surplus, which accounts for responses to price changes in aggregate (i.e., on the part of a representative household in the CGE model). Williams et al. (2015) found that differences in distributional effects across revenue recycling options were primarily driven by household differences in sources of income.

It is important to note that accounting for this behavioral response in aggregate implies the assumption that all households have the same elasticity of demand for consumption goods and elasticity of supply for factors of production. If households vary in how they respond to the carbon tax on the basis of income, this effect is missed by the models. As is the case for U.S. EPA (2010c) and Burtraw et al. (2009), because household responses are not fed back into the CGE model to iteratively estimate the price and quantity changes, aggregation is imperfect in Williams et al. (2014, 2015) and Gordon et al. (2015).

### *5.5.3 CGE models with some heterogeneity in the household sector*

Several studies that evaluate effects of environmental policy on household income distribution use a CGE model that explicitly integrates the behavior of different types of households into the model itself. These types of CGE models typically assume perfect aggregation; households are divided into groups that are assumed to have identical within-group consumption and labor supply preferences. We discuss a few examples from the literature below.<sup>58</sup>

Rausch et al. (2010) used the USREP model to analyze the distributional and efficiency impacts of different allocations of allowances in a greenhouse gas cap and trade policy across the model's nine different income groups and twelve geographic regions within the United States. The USREP model is a recursive dynamic CGE model of the U.S., built from the state-level IMPLAN dataset, similar in structure

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<sup>58</sup> The Joint Committee on Taxation (JCT) has a highly aggregate in-house DSGE model (i.e., with one production sector) that differentiates between savers and spenders. Spenders are defined as households with positive labor income in the bottom 40<sup>th</sup> percentile. The JCT (2011) notes that this allows them to examine the differential effects of proposals on relatively low and high-income households, though - as already noted - results from the DGSE model are not typically included as part of its reports to Congress (JCT, 2015).

to the MIT Emissions Prediction and Policy Analysis (EPPA) model. The policy modeled in Rausch et al. (2010) is cumulative cap on U.S. GHG emissions through 2050, approximating the cap levels in proposed legislation of the time, and the allowance allocations examined include approximations of the Waxman-Markey, Kerry-Boxer, and Cantwell-Collins proposals. The paper found that carbon pricing on its own was proportionally to modestly progressive, and the various allowance allocation mechanisms resulted in policies that were progressive over the lower half of the income distribution and proportional in the upper half of the income distribution. The paper examined both the source side (impacts from changes in relative factor prices) and use side (impacts from changes in relative product prices, typically regressive due to the higher proportion of income spent on energy by low income households) distributional effects. As in Williams et al. (2015), they found that the overall distributional effects were primarily driven by income source effects. This result was at least partially driven by scenarios holding government transfers (a large fraction of income for the lower portion of the distribution) constant in real terms, so they were unaffected by carbon pricing, while labor and capital income was affected.

Jorgenson et al. (2011) used the Intertemporal General Equilibrium Model (IGEM) to analyze the distributional impacts of an approximation of the Waxman-Markey greenhouse gas cap and trade policy across household types based on equivalent variation in full wealth (i.e., the value of goods and services as well as leisure). IGEM is an econometrically estimated dynamic CGE model of the U.S. with perfect foresight, consisting of four sub-models for the household, production, government, and rest of the world sectors. The household consumption sub-model distinguishes between 244 demographic groups based on number of children, number of adults, region, location (urban or rural), gender of head of household, and race of head of household. (As with the other papers discussed in this section, these data are derived from the U.S. Consumer Expenditure Survey.) The sub-model allocates full wealth across time, then between leisure and three commodity groups (nondurables, capital services, and services) for each period, and then across 35 individual commodities within the three commodity groups. The paper found that roughly one fifth of the households experienced a small welfare loss, while the remaining households gained slightly, and the equivalent variation became less negative (or more positive) as full wealth increased across household types. Thus, the overall distributional impact of the climate policy was regressive when measured in terms of the equivalent variation of full wealth.

As previously mentioned, highly disaggregated micro simulation models are sometimes used to examine the implications of a policy shock on individual household behavior (see Williams et al., 2014, 2015; and Gordon et al., 2015). Rarely are these behavioral changes fed back into a CGE model to generate predictions of changes in aggregate prices and quantities that are then passed along, again, to the household model. Rausch et al. (2011) used an iterative approach to endogenously incorporate highly disaggregate household decision-making (based on the Consumer Expenditure Survey data) into the US REP model. In this way, unlike previous studies discussed, they ensured perfect aggregation: absent the policy, iteratively solving the representative agent CGE model, US REP, and the highly disaggregated partial equilibrium household model one is able to replicate the benchmark equilibrium. Consistent with other studies, Rausch et al. (2011) found that accounting for households' sources of income reduced the regressivity of the policy based only on household consumption. They pointed to several factors driving this result: First, returns on capital fell relative to wages in the model, and since capital income is a large

share of income for the richest households they experienced relatively negative impacts compared to lower income households. Second, as in Rausch et al. (2010) government transfers were held constant. Third, the model assumed a closed economy, which means capital cannot shift to other economies without a carbon price, though as the authors noted, the effect of this assumption is difficult to predict since households were also precluded from shifting consumption to unpriced alternatives.

## 6. Concluding Remarks

While EPA has a range of methods and tools available to evaluate the ways in which economic impacts of an air regulation are distributed across sectors, households, and time, it typically has relied on engineering and partial equilibrium approaches to estimate them. However, because CGE models capture interactions between economic sectors sometimes missed by these other approaches, an economy-wide model could add value beyond the tools already in use for identifying impacts outside of the directly regulated sector. EPA seeks guidance from the SAB Panel on how to weigh the technical merits and challenges of using CGE models or other economy-wide approaches when estimating the economic impacts of air regulations. In particular, EPA is interested in understanding:

- To what extent CGE models are technically appropriate for shedding light on: short and long run implications of energy prices for households and firms, sectoral impacts, impacts on households on the basis of income, transition costs, and equilibrium impacts on labor market outcomes?

To help inform discussion of this question, the paper offer a description of: the types of economic impacts typically of interest to policymakers when proposing or finalizing an air regulation; when CGE models been used by EPA to evaluate economic impacts; and key CGE model features and issues from the academic literature potentially relevant to the analysis of the economic impacts of air regulations.

Organizations outside the federal government have also used CGE models to assess the economic impact of recent EPA air regulations. Most of these studies exist in the grey literature and have not been formally peer reviewed. In this context, EPA is interested in guidance regarding:

- What criteria should be used to evaluate the scientific defensibility of CGE models to evaluate economic impacts?

To help inform this question, the paper provides a brief overview of the types of models used by outside organizations to conduct economy-wide analyses of the economic impacts of specific EPA air regulations, which includes CGE, input-output, and I-O macro-econometric approaches.

Several of the charge questions pertain specifically to estimation of labor market impacts of air regulations in an economy-wide model:

- What types of labor impacts (can be credibly identified and assessed by a CGE model in the presence of full employment assumptions? How should these effects be interpreted?

- Are there ways to credibly loosen the full employment assumption to evaluate policy actions during recessions?
- Are there ways to credibly relax the instantaneous adjustment assumptions in a CGE model in order to examine transition costs such that it provides valuable information compared to partial equilibrium analysis or other modeling approaches?

To aid the SAB in responding to these questions, the paper describes: metrics used by outside and EPA studies to characterize employment impacts of air regulations; what economic theory predicts with regard to labor market impacts in the context of environmental regulation; peer-reviewed, published literature on environmental regulations and labor market impacts; how labor markets are typically structured in a CGE model as well as alternative approaches used to-date.

The charge also asks:

- Are there other economy-wide modeling approaches that EPA could consider in conjunction with CGE models to evaluate the short run implications of an air regulation?
- What are the advantages or disadvantages of these approaches?

In addition to the discussion of economy-wide approaches used by outside organizations, the paper briefly discusses input-output, I-O macro-econometric, and DSGE modeling approaches that have been used in the academic literature to examine labor and sectoral impacts of environmental policy.

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