A Computable General Equilibrium Model of Energy Taxation with Endogenous Resource Supply and Flexible Substitution

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April 2014

Abstract

In this paper, I construct a new general equilibrium model of the United States economy that is better able to analyze energy taxes than previous models. Existing models in the energy literature fall into two groups: general equilibrium models of the entire economy with exogenous energy resource supply and partial equilibrium models of the energy sector with endogenous resource supply. I combine the main advantages of these two strains of the literature by incorporating endogenous resource supply in a computable general equilibrium model with highly disaggregated and flexible industry cost and consumer expenditure functions. My new model is able to analyze all the major inefficiencies caused by energy taxation, i.e., those related to production, consumption, resource rents, and externalities.

My model is then used to analyze the effects of numerous proposed changes to the taxation of fossil fuels in President Obama’s 2014 budget, which would impose additional taxes on the energy sector. This analysis reaches three main conclusions. First, the impact of the provisions in the budget proposal on the neutrality of the tax code is ambiguous: some provisions move toward neutrality in taxation as advocated in the literature while others do not. Second, the budget proposal will reduce domestic fossil fuel production and will also reduce household welfare before carbon externalities are accounted for. The social cost of carbon needs to be at least $14 per ton in order for reduced carbon emissions to make up for the social efficiency costs of the budget proposal. Third, the innovations in my model significantly impact the estimates of the proposal’s effects. A general equilibrium model without flexible substitution would overstate the proposal’s reduction in carbon emissions or understate the efficiency loss from input substitution. Similarly, a model without externalities would underestimate the benefits of the proposal. In addition, sensitivity tests illustrate that both the inclusion of an energy resource and the general equilibrium effects of import substitution have important welfare impacts. Overall, these results demonstrate that the predicted impacts of the budget proposal significantly change due to the features included in my model: general equilibrium effects, flexible substitution, resource rents, and externalities.

Keywords: Computable General Equilibrium, Tax Policy, Resource Rents, Translog, Fossil Fuels.

JEL Classification Codes: C68, H21, Q43, Q48.

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1 Introduction

Federal corporate income tax reform is a perennial topic of scholarly discussion among public finance economists in the US. The tax code is rife with deductions and exemptions that could be eliminated in order to broaden the tax base and lower its rate. In particular, fossil fuels have been a target of President Obama’s budgets in recent years. The president’s 2014 budget would eliminate $144 billion worth of provisions it identifies as tax preferences for fossil fuel production (Treasury, 2013).

The Obama administration makes a standard tax neutrality argument to justify the budget’s tax changes. In general, a tax is considered neutral if it does not influence economic choices such as which inputs or technologies are used for production, how investment is allocated across assets or industries, how firms are organized, or how investments are financed. Tax neutrality is beneficial because it is necessary for production and consumption efficiency. Unfortunately, experts disagree which parts of the tax code — e.g., tax credits, deductions, or tax rates — are neutral.

However, it is not the individual parts but the tax code as a whole that should be neutral. This is because the neutrality of individual tax provisions only matters in so far as they determine the neutrality of the tax code as a whole. Therefore, in order to determine if the proposed changes increase tax neutrality, the entire code must be examined, not just these particular provisions. The ultimate question then is not merely whether these individual provisions favor fossil fuel production, but whether the tax code as a whole does. Unfortunately, this type of descriptive analysis can only go so far before formal economic models are necessary.

There are two general categories of models in the energy taxation literature. The first takes a partial equilibrium (PE) approach that models energy resource development in great detail but has a highly simplified representation of the rest of the economy. The second uses a computable general equilibrium (CGE) approach that models many production sectors in the economy but has little detail on the differences between energy extraction and other sectors. Therefore both of these methods are missing a key feature that the other has.

This paper builds a new model that combines the most important features of both approaches. My model is a computable general equilibrium model of the US economy that includes both endogenous resource supply and externalities. Moreover, I use translog cost and expenditure functions that allow for flexible substitution by firms across inputs and by consumers
across goods. The resulting model allows a comprehensive analysis of the three primary areas in which energy taxes may create or reduce inefficiencies: production and consumption, resource rents, and externalities.

First, energy taxes can cause production and consumption inefficiencies because they violate the principle of tax neutrality, which states that taxes should not distort choices between economic activities. If tax rates differ between different goods, firms and consumers who use these goods will substitute to use less of the more taxed good and more of the less taxed good. Substitution will minimize the firm or consumer’s post-tax private costs but will increase their pre-tax or social costs. This leads to productive and consumptive inefficiency.

Because energy taxes create inefficiencies via substitution, accurate modeling of input and consumer substitution is critical for understanding the effects of energy taxation. Nevertheless, almost all partial equilibrium models assume exogenous energy prices and therefore cannot include any of these three efficiency effects (Lund, 2009). But the treatment of energy taxes in most CGE (computable general equilibrium) models is also problematical. CGE models such as Zodrow and Diamond (2013) that utilize constant elasticity of substitution (CES) or Cobb-Douglas functions for consumer expenditure constrain the substitutability between all goods to be the same (Uzawa, 1962). By comparison, Altig et al. (2001), Fullerton and Rogers (1993), and other models with fixed coefficients do not allow consumer substitution at all. Moreover, these papers’ firm production functions also have the same problems because those functions are CES, Cobb-Douglas, or fixed coefficient as well. Limiting the possibilities for input substitution will overestimate the impact of energy taxes on firm costs. Therefore neither PE nor CGE models accurately model substitution. Jorgenson and Yun (2001) is a notable exception that informed my model. Jorgenson and Yun (2001) and my model both use a highly flexible translog functional form for the firm cost functions (and consumer expenditure function) that allows varying degrees of substitutability between different pairs of inputs (consumer goods).

The second source of energy tax inefficiency is the tax treatment of resource rents. If the energy resources (i.e., the coal, oil, or gas in the ground) have perfectly inelastic supply, then their factor payments would be economic rents and taxing them would be non-distortionary.

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1The principle of tax neutrality requires that no externalities exist. However, since there are many externalities to fossil fuel consumption, I must also consider the effect of externalities when determining the efficiency of energy taxes.

2Nested CES can be used to add some flexibility. However, this is typically used only at the top level with fixed coefficient functional forms at lower levels. Substitution remains inflexible for any inputs which are not nested and the resulting substitutability is not invariant to the nesting structure (Sato, 1967).

3See section 3.2.3.1 for a detailed description of the translog cost function.
In such a case, non-distortionary resource rent taxes would be more efficient than distortionary
taxes on other sectors. In order to determine if rents exist, a model must determine whether
changes in energy taxation affect the supply of energy resources. The partial equilibrium liter-
ature contains many such models of energy supply. For example, the PE approach developed
initially by Hotelling (1931) is commonly used to model the decision to develop and extract en-
ergy resources. Dasgupta, Heal, and Stiglitz (1981) extended the Hotelling (1931) framework to
show how taxation affects resource extraction. Some stylized general equilibrium models, such
as Solow and Wan (1976), have featured similar resource modeling. However, firm resource sup-
ply decisions are usually much simpler in CGE models than in PE models, if resource supply
is modeled at all in the CGE model. Some CGE models have exogenous supply of the resource
that is invariant to price (Babiker et al., 2008; Paltsev et al., 2005). Other CGE models do
not include an energy resource at all (Altig et al., 2001; Fullerton and Rogers, 1993; Jorgenson
and Yun, 2001; Zodrow and Diamond, 2013). By contrast, my model is a CGE model and
yet includes endogenous energy resource supply. By varying the own price elasticity of energy
resource supply, my model can determine the impact of the taxation of resource rents on the
efficiency of energy taxes.

The third way that energy taxes lead to economic inefficiency is the treatment of externali-
ties. Fossil fuels are associated with externalities relating to air pollution, climate change, and
energy security. By definition, externalities are not internalized in the private costs borne by the
producers and consumers of a good that creates an externality. Pigouvian taxes on externalities
can internalize the social costs they create, leading market participants to choose the socially
optimal level of the activity. Many CGE models, such as Paltsev et al. (2005) and Babiker et al.
(2008), incorporate carbon externalities.

In this paper, I construct a CGE model of US energy taxation that improves on previ-
ous models by including all three sources of tax inefficiency. My model contains a number of
features that allow it to capture each of the three issues. In order to accurately model both
consumer substitution across goods and producer substitution across inputs, I utilize a highly
disaggregated cost and expenditure functions with transcendental logarithmic (translog) func-
tional forms. There are 22 production sectors, with each producing a single output using capital,
labor, and potentially all of the 22 outputs as inputs. These outputs are also all used for the
final consumer goods. The translog form allows for varying degrees of substitutability between
inputs (capital, labor, energy, and other goods) in the production and consumption of each
good.

Because the cost and expenditure function parameters are so critical to the model, I take several steps to ensure that they are accurate. The parameter values are estimated from five decades of data using regression analysis, not calibrated, so that my results are not driven by the idiosyncrasies of the specific year used for calibration. I perform a number of statistical tests on the data to confirm that the regression specification is appropriate. Moreover, I ensure the parameter values make economic sense by testing for the concavity and monotonicity of the ensuing cost function. To investigate the sensitivity of model efficiency estimates to these parameters, I also calculate efficiency estimates using a number of alternate specifications and perform Monte Carlo analysis to calculate confidence intervals for the model’s predictions.

As previously discussed, energy production in the model requires energy resources. The model assumes a constant elasticity of supply of energy resources. This elasticity of supply can be varied to change the responsiveness of the energy resource to changes in rents. I vary this supply elasticity from 0.1, where resource supply is relatively unresponsive to changes in rents, to 1.0, where the energy resource is more responsive to own price changes than capital is. And finally, negative externalities from fossil fuel production are included.

Beyond these innovations for improved modeling of energy taxation, my CGE model follows the existing CGE literature. All goods and inputs are supplied endogenously. The aggregate demand for exports and supply functions for capital and labor are assumed to be isoelastic, which facilitates the use of parameter values found in previous empirical research.\(^4\) The ratio of imports to domestic production is determined by their relative prices through a constant elasticity of substitution cost function. Existing government taxes on capital, labor, and production are modeled explicitly.

Once my model is constructed, I assess it by analyzing energy tax changes in President Obama’s fiscal year 2014 budget proposal. Supporters state that president’s budget will make the tax code more neutral by eliminating tax preferences for fossil fuel production. However, thus far the only analysis of these changes are descriptive judgments based on principles of neutral taxation. In this paper, I provide additional descriptive analysis of the budget but I also use my model to estimate the actual economic effects of the proposal, which were previously unknown.

The overall outline of the paper is as follows. In section 2, I provide descriptive analysis of

\(^4\) An isoelastic function has the form \(f(x) = kx^r\) and has elasticity \(r\).
the fossil fuel tax changes in President Obama’s 2014 budget proposal. I examine whether the provisions changed by the budget are in fact tax preferences and compare the budget’s proposed changes to both current law and the tax treatment of that issue under a neutral tax system. The budget proposal typically identifies areas in need of reform but then proposes changes different from the treatment of those issues under a neutral tax system.

Then in the latter half of the paper, I discuss my new model of energy taxation and its application to the budget proposal. In section 3 I construct a computable general equilibrium model of the US economy with endogenous resource supply, flexible substitution, and externalities. I describe the model equations, the data used to parametrize these equations, and other assumptions. I then use the model to simulate the macroeconomic effects of the president’s budget proposal in section 4. I find that the budget proposal will reduce domestic fossil fuel production. It will also reduce household welfare before carbon externalities are accounted for. The social cost of carbon needs to be at least $14 per ton in order for reduced carbon emissions to make up for the social efficiency costs of the budget proposal.

My model is not merely more general than previous models, but in fact the innovations combined in my model significantly impact the estimated effects of the budget proposal. A general equilibrium model without flexible substitution would overstate the proposal’s reduction in carbon emissions or understate the efficiency loss from input substitution. Similarly, a model without externalities would underestimate the benefits of the proposal. By contrast, my model address both of these pitfalls. Furthermore, sensitivity tests illustrate that both my model’s inclusion of an energy resource and the general equilibrium effects of import substitution also have important welfare impacts. Taken together, the results confirm the importance of my model’s inclusion of general equilibrium effects, productive and consumptive efficiency, resource rents, and externalities.

2 Energy Taxation in the President’s 2014 Budget

2.1 Overview

President Obama’s 2014 budget proposes to raise billions of dollars in tax revenue by increasing taxes on fossil fuel production. The president himself noted that “these companies pay a lower tax rate than most other companies on their investments, partly because we’re giving them billions in tax giveaways every year” (Office of the Press Secretary, 2012). The budget
Table 1: Revenue Estimates of Provisions of the President’s 2014 Budget for 2013-23 ($ millions)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeal LIFO inventory accounting for all sectors</td>
<td>78,299</td>
<td>80,822</td>
</tr>
<tr>
<td>Repeal the domestic manufacturing deduction for fossil fuels</td>
<td>19,881</td>
<td>17,856</td>
</tr>
<tr>
<td>Repeal expensing of intangible drilling costs</td>
<td>13,698</td>
<td>10,993</td>
</tr>
<tr>
<td>Repeal percentage depletion for oil and gas</td>
<td>11,118</td>
<td>10,723</td>
</tr>
<tr>
<td>Repeal percentage depletion for coal and other hard mineral fossil fuels</td>
<td>595</td>
<td>1,982</td>
</tr>
<tr>
<td>Repeal expensing of coal exploration and development</td>
<td>591</td>
<td>432</td>
</tr>
<tr>
<td>All other fossil fuel specific provisions</td>
<td>270</td>
<td>181</td>
</tr>
<tr>
<td>Total</td>
<td>144,218</td>
<td>144,838</td>
</tr>
</tbody>
</table>

Notes: (1) This is the revenue estimate for all 3 Superfund excise taxes combined. However, only one of the three, a tax on petroleum, is relevant to the energy industry. But from 1991-1995 this one tax accounted for 68% of the total revenue of the three taxes (Ramseur, Reisch, and McCarthy, 2008).

The Obama administration has invoked tax neutrality to justify the budget’s tax changes. Tax neutrality is a useful concept because previous work has shown that under certain assumptions, neutral taxes are both socially efficient and sufficient to achieve redistributive goals (Atkinson and Stiglitz, 1976; Diamond and Mirrlees, 1971). In particular, tax neutrality is

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5 The statutory tax rate is the legally imposed rate on taxable income. Effective tax rates are a more robust measure of taxation that also includes the effect of credits, deductions, the timing of payments, etc. See appendix C for more details.
6 Although JCT (2012) analyzes the 2013 budget proposal, the proposed changes to fossil fuel taxation are virtually identical to those in the 2014 budget proposal.
7 Treasury does not elaborate on how tax preferences that encourage domestic fossil fuel production reduce energy security.
8 See also Hammond (2000) and Hellwig (2008).
necessary for production and consumption efficiency. Neutrality is thus a proxy for efficiency that is easier to measure. This means that in addition to the negative consequences cited by Treasury, favoritism of fossil fuels could decrease social welfare. Unfortunately, measuring neutrality is still difficult and scholars disagree over the exact traits of a neutral tax system. However, the key question is not merely whether these individual provisions favor fossil fuel production, but whether the tax code as a whole does. In this section, I analyze the neutrality of the provisions, before moving on to examine their combined effect using the model presented in section 3.

The organization of this section is as follows: in section 2.2 I discuss each change proposed in the 2014 budget that is relevant to fossil fuel production. I examine whether the provisions changed by the budget are in fact tax preferences, and if so, whether the proposed change successfully addresses the issue. I do so by comparing the budget’s proposed changes to both current law and the tax treatment of that issue under a neutral tax system.

2.2 Individual Provisions of the Budget Proposal

2.2.1 Last-in, First-out (LIFO) Inventory Accounting

Last-in, First-out (LIFO) is a system of inventory accounting that determines firm tax deductions. Under current law, taxpayers are allowed to deduct the cost of acquiring the goods they sell. However, the appropriate cost becomes unclear when the firm is selling goods from an inventory containing goods acquired at different times, each of which was bought at a different price. The LIFO and FIFO methods determine which price to use in this situation. Under last-in, first-out (LIFO), when a unit of a good is removed from inventory, the price of the last (most recent) unit of that good put into the inventory is used to calculate net income from the sale of the good. Under first-in, first-out (FIFO), when a unit of a good is removed from inventory, the price of the first (least recent) unit of the good put in inventory is used to calculate net income from the sale of the good.

LIFO and FIFO can give significantly different prices and deductions. When the price of an inventory item is increasing, such as due to inflation, the cost of goods sold is higher under LIFO than FIFO. A higher cost of goods sold in a period translates to lower net taxable income

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9I refer to production efficiency in the same sense as Diamond and Mirrlees (1971).
10See Congressional Budget Office (2011), hereafter CBO, for a description of LIFO, FIFO, and the “specific identification” inventory accounting methods, their interaction with “lower of cost or market” changes, and arguments for and against them.
and thus lower taxes paid in that period. The lower cost of goods sold from the less recent period is not used until inventories are drawn down. But if inventories are never drawn down, this lower cost of goods sold is never used and those inventory items’ appreciation, whether inflationary or not, is never taxed.

Although LIFO accounting is not unique to firms that produce fossil fuels, LIFO is disproportionately used by firms in the energy sector. Energy companies account for more than 82 percent of the LIFO reserves of all companies on the S&P 500 Index (Przybyla, 2011). Energy companies also use LIFO more than other firms both as a fraction of inventories and by dollar value. LIFO reserves average $2.6 billion or 199% of inventories for oil and gas firms that use LIFO. For firms in other sectors that use LIFO, LIFO reserves range from $13 million up to $150 million and from 2 to 28 percent of inventories (Tipton, 2012). In addition, among corporations with inventories valued at over 1 million dollars, overall only 23 percent of inventories are LIFO. But for the petroleum refining, 73 percent of inventories are LIFO (Knittel, 2009).

President Obama’s 2014 budget proposal would repeal the LIFO inventory accounting method for income tax purposes, regardless of the use of LIFO on the firm’s financial statement (Treasury, 2013). Taxpayers that currently use LIFO would be required to write up their beginning LIFO inventory to its FIFO value in the first taxable year beginning in 2014 (Treasury, 2013). The resulting increase in income is taken into account ratably over 10 years (Treasury, 2013).

In a neutral tax system, taxes would be imposed on real economic income, not increases that are attributable to inflation. Gains from inflation would not be taxed, but neither would an incentive be created to retain inventories. And inventory appreciation that is not due to inflation would be taxed. In contrast to the president’s proposal, Treasury (1984) recommends achieving these goals by allowing firms to choose between FIFO indexed for inflation or LIFO. Conversely, as previously noted, LIFO allows firms to defer taxes on the gains from their inventory appreciating by maintaining their inventory stock. So I recommend mandatory inflation indexed FIFO as the ideal method. However, the president’s proposal is for non-indexed FIFO. Without indexing, it is unclear if the FIFO requirement proposed by the president would be more or less neutral than the current system.

Kleinbard, Plesko, and Goodman (2006) notes that inflation affects all capital investment, not just inventories. Therefore, they say that inflation should be dealt with in a systematic manner instead of through LIFO. They contend that LIFO is a piecemeal solution affecting only inventories and thus favors investment in inventories over other forms of investment. This argument on the theory of the second best adds another layer of ambiguity.
2.2.2 Domestic Manufacturing Deduction

The domestic manufacturing deduction was added to the tax code with the American Jobs Creation Act of 2004 with the intent of encouraging domestic investment and improving the competitiveness of US manufacturers in global markets (Blouin, Krull, and Schwab, 2007). It allows a taxpayer to deduct a percentage of their income derived from domestic manufacturing activities (Pirog, 2012). The percentage of the deduction is six percent for oil and gas production and is nine percent for other qualifying industries. The president’s 2014 budget proposal would repeal the domestic manufacturing deduction for income derived from the domestic production of oil, gas, coal, and other hard mineral fossil fuels (Treasury, 2013).

There are two margins on which this change needs to be considered: which industries receive the deduction and imports versus domestic production. In regards to first issue, the change would level the playing field between fossil fuels and industries that do not receive the deduction. But it would also increase the gap between still deductible industries and fossil fuels. The second dimension of the change is the choice between domestic production and importation. Eliminating the deduction would increase the favorability of importing fossil fuels instead of domestic production. Although this paper will not attempt to weigh the merits of energy security against free trade, Treasury (2013) has mentioned improving energy security as one of the reasons for the tax changes. This provision of the budget proposal would not accomplish this goal: increasing the favorability of importing fossil would actually reduce US energy security.

2.2.3 Expensing of Intangible Drilling Costs

Intangible drilling costs (IDCs) are expenditures made in preparation of wells for the production of oil, natural gas, or geothermal energy that are not for the purchase of tangible property. For example, wages and fuel are examples of IDCs but pipelines are not (Treasury, 1984). Most taxpayers may elect to either expense or capitalize these costs. Integrated oil and gas companies, however, are not allowed to fully expense IDCs but must capitalize 30% of intangible drilling expenses over a 60-month period (JCT, 2012).12

The president’s 2014 budget proposal repeals both the expensing and 60-month amortization of IDCs for all firms (Treasury, 2013). Intangible drilling costs instead would be capitalized as depreciable or depletable property (Treasury, 2013).13 Although the expensing of intangible

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12 Integrated oil and gas companies refer to oil and gas producers that conduct production, refining, and retail sales activities. (JCT, 2012).
13 Typically, depreciable assets are used to recover depletable assets (JCT, 2012).
drilling costs is not exclusively for oil and natural gas but also allowed for geothermal energy, both JCT (2012) and Treasury (2013) only discuss repeal for fossil fuels, not geothermal.

Under a neutral income tax system, expenses relating to the creation of a capital asset should not be expensed, but capitalized, with the tax depreciation allowance equal to the economic depreciation rate of the capital asset produced. However, it is not clear what generally applicable rules would then apply to IDCs nor what the true rate of economic depreciation is. It is thus not possible to compare whether the old or new rates are closer to the economic rate of depreciation. However, one clear advantage of this change is that it would remove the different tax treatment between firms due to organizational form since it would remove a deduction not available to integrated oil companies.

2.2.4 Percentage Depletion

Depletion deductions are similar to depreciation deductions. They are both deductions taxpayers receive as capital is reduced in value as it produces income. For fossil fuels, the cost of acquiring the lease for a property’s mineral rights is deductible through depletion, not depreciation (JCT, 2012). The tax code recognizes two methods for the calculation of depletion deductions: cost depletion and percentage depletion.

Under the cost depletion method, each year the taxpayer deducts an amount equal to the amount of the resource recovered that year times the cost of acquiring the lease divided by the total amount of the resource in the property. Under the percentage depletion method, a constant percentage, varying from five to 22 percent (depending on the type of resource extracted) of the taxpayer’s gross income from a producing property is allowed as a deduction from net income in each taxable year (JCT, 2012).

A disadvantage of percentage depletion is that it does not depend on the costs of acquiring the property and thus has no direct relationship to cost recovery. Over the years 1968-2000 government revenue was decreased by a total of $82 billion in year 2000 dollars because of the

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14 There is no reference in the proposal to what the new rules are or if there even is a single set of rules which would now apply to all IDCs. It appears that expenditures that are currently grouped together under the category of IDC would have a variety of different treatments.

15 See CBO (2011) for further discussion of this issue.

16 Additional explanation of the two depletion methods is available in Internal Revenue Service (2011a), hereafter IRS.

17 Other limitations on percentage depletion exist as well. For example, for non-integrated oil companies, the deduction is limited to domestic US production on the first one thousand barrels per day per well and is also limited to 65 percent of net income on that particular property. Integrated oil companies are not allowed to use the percentage depletion deduction at all (Smalling, 2012).
greater deductions available to the petroleum industry in percentage depletion compared to cost depletion (U.S. General Accounting Office, 2000). In addition, cumulative depletion deductions may be greater than the amount expended by the taxpayer to acquire the property in the first place (JCT, 2012).

The president’s 2014 budget proposal would repeal the percentage depletion deduction for fossil fuels but retain it for other mining (Treasury, 2013). All properties and firms engaged in fossil fuel extraction would use the cost depletion method instead (Treasury, 2013).

In isolation, percentage depletion is non-neutral. The percentages are chosen based on non-economic criteria such as the type of resource being extracted and eligibility varies depending on firm organizational form. Percentage depletion is also not directly linked to the cost of the actual capital invested. If this tax were revised to be neutral, is unclear what the optimal depreciation rate would be. But using the rate at which minerals are removed from the property as the depreciation rate (as cost depletion does) would at least ensure that full write off only occurs when all the minerals are removed from the property. So it appears to be a more neutral method than using percentage depletion.

However, including other taxes into the analysis increases the favorability of percentage depletion. In 2011, 35 of the 50 states imposed a severance tax on the extraction of natural resources (Telles, O’Sullivan, and Willhide, 2012). These taxes are usually imposed at a flat rate per unit of the commodity (per ton of coal, per barrel of oil, etc.) (Zelio and Houlihan, 2008). As shown in Table 13 of appendix C.1, aggregate revenue from severance and all other production taxes for oil and gas extraction averages $20 billion per year. Such taxes are distortionary because they reduce the marginal revenue of additional extraction compared to its marginal cost, causing early shutdown of otherwise still productive property. A percentage depletion allowance less than or equal to the severance tax rate would be efficiency enhancing by effectively canceling out part of the severance tax and thus increasing production.

In addition, the percentage depletion deduction is repealed for fossil fuel extraction but not all resources. However the arguments for and against percentage depletion in fossil fuel extraction also apply to mining for other resources, which would retain their percentage depletion deduction under the proposal. By contrast, under a neutral tax system all forms of extraction

\footnote{Although using percentage depletion to cancel out these taxes would mean the original purpose of the depletion deduction, recovering capital costs incurred in acquiring the property, would not be served. Additionally, this means that federal tax law is being used to eliminate inefficiencies in state tax law. Although not relevant for determining tax neutrality, the appropriateness of such a use of federal law raises important political issues.}
would have uniform depletion rules that do not vary based on the resource extracted.

This means that the repeal of percentage depletion has two effects. It increases the neutrality of the code because percentage depletion is itself distortionary. However, it reduces the neutrality of the code by eliminating a deduction that offsets other distortionary taxes and also by favoring non-fossil fuel resource extraction over fossil fuel extraction. It is necessary to calculate the relative size of the two components in order to determine if the net effect is efficiency enhancing or reducing. Therefore the descriptive analysis conducted so far can not determine the neutrality of this provision.

### 2.2.5 Oil Spill Liability Trust Fund

Currently an excise tax of 8 cents per barrel is imposed on crude oil produced in the US and crude oil and petroleum products imported into the US. This tax is scheduled to increase to 9 cents per barrel during 2017 and then expire in 2018. However, the excise tax has been repeatedly extended since its creation in 1990 and is assumed to be permanent for federal budget scorekeeping purposes (JCT 2011).

The proceeds from this excise tax are deposited in the Oil Spill Liability Trust Fund, which is used to pay for various costs resulting from oil spills and their subsequent cleanup (Treasury, 2013). The fund pays for claims that are not covered by the responsible party, up to a $1 billion per incident limit and can reimburse the responsible party for some oil spill cleanup costs if the spill was not caused by negligence or violation of federal regulations. The fund also pays for government oil spill prevention and response programs (Treasury, 2013).

For the purposes of this tax, “crude oil” does not include synthetic petroleum or unconventional crudes. This means that domestically produced shale oil, refined oil, and liquids from coal, tar sands, and biomass are not taxed (JCT, 2012). Refined oil is taxed if imported because it is included under “petroleum products” but imported tar sands are not (IRS 2011).

The president’s 2014 budget proposal increases the excise tax to 9 cents per barrel for 2014-2016 and to 10 cents per barrel for 2017 and onwards (Treasury, 2013). The tax would also be extended to apply to crudes that are produced from bituminous deposits and kerogen-rich rock, e.g. shale oil (Treasury, 2013).

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19 The excise tax rate is also called the financing rate.
20 Responsible parties are reimbursed for cleanup costs over a fixed amount that depends on the size of the vessel or facility the spill occurred at. However, Woods (2008) notes that the standards used to prove that the responsible party was not negligent can make it difficult for responsible parties to receive this reimbursement.
In the case of smaller oil spills, strict civil liability for the full costs of the oil spill is optimal as it fully internalizes both the cost of the oil spill and the cost of prevention. The main argument for a trust fund is the case of catastrophic oil spills where the damages exceed the ability of the responsible party to pay. Previous literature has advocated two solutions to dealing with catastrophic oil spills: mandatory insurance and a prospective excess liability tax (Cohen et al., 2011; Viscusi and Zeckhauser, 2011). Under a prospective excess liability tax, responsible parties would still face full strict liability but a tax would also be imposed and the federal government would pay for any damages that exceed the value of the responsible party’s assets. This tax’s rate would need to be actuarially fair with respect to the probability the activity causes an accident that could not be covered by the responsible party’s assets.

The excise tax used to fund the Oil Spill Liability Trust Fund is much closer to a prospective excess liability tax than mandatory insurance, so that is the comparison I will make to judge the neutrality of the tax. However, the trust fund’s excise tax differs from a prospective excess liability tax in two ways: it does not have an actuarially fair rate and has only limited liability. And the president’s proposal to increase the excise tax rate and extend it to other forms of oil production would make the difference even larger.

The Oil Spill Liability Trust Fund excise tax differs from a prospective excess liability tax in a number of key areas. A prospective excess liability tax has an actuarially fair tax rate equal to the expected cost to the trust fund per barrel produced. However, there is no evidence the current rate of 8 cents per barrel or the president’s proposed increase to 9 cents per barrel are based on the expected cost to the trust fund. And ideally, the rate would also vary with the level of safety taken by the firm, although the benefits of a more accurate rate need to be weighed against the difficulty of administrating such a tax. Additionally, extending the tax to include unconventional deposits is problematic. Taxing onshore and offshore oil production at the same rate is not actuarially fair if catastrophic onshore oil pollution has a lower cleanup cost or likelihood than offshore. This could easily be the case because spills from the extraction of crude from oil sands onshore (or in fact, any onshore oil extraction) are easier to repair structures for and bring responders to when compared with oil spills that occur offshore like the Deepwater Horizon (Macondo).\footnote{Although they do not calculate cleanup costs per barrel produced, comparison of onshore cleanup costs estimated by Connor et al. (2011) and offshore costs by Kontovas, Psaraftis, and Ventikos (2010) illustrate the markedly higher price of offshore cleanup.}

In addition, it is worth noting that the purpose of the tax is to pay for catastrophic oil
spills that exceed the responsible party’s ability to pay, not smaller oil spills for which the responsible party can pay. Thus a neutral tax rate would also need to take into account the lower rate of default for large firms with deep pockets by charging them a lower excise tax rate on oil production. The Deepwater Horizon oil spill cost BP $42.2 billion as of February 2013, far exceeding the Oil Spill Liability Trust fund’s $1 billion cap (Fontevecchia, 2013). The probability that an oil spill would exceed the roughly $100 billion assets of a major integrated oil company like BP would be extremely small, and thus the actuarially fair tax rate would be similarly small (Abraham, 2011). This is one of the few places in the tax code where different tax treatment of small firms and major integrated oil companies can be justified.

Although firms would face full strict civil liability under a prospective excess liability tax regime, under current law liability is limited in two ways. First, total payouts by the trust fund are limited to $1 billion per incident. But with this cap, the trust fund could not fully cover the damages of the Deepwater Horizon oil spill if BP had defaulted. And second, the trust fund limits the liability of responsible parties for oil spills if they were not negligent and did not break federal regulation. This creates a moral hazard for firms to follow the minimum level of oil spill avoidance required by law, instead of the socially optimal level ensured by full strict civil liability.

2.2.6 Superfund Excise Taxes

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 established the Superfund program to clean up heavily polluted locations across the US. Following the act, the Environmental Protection Agency began maintaining a list of polluted sites called the National Priorities List. For 70 percent of the sites on the list, the EPA can locate one or more potentially responsible parties (PRPs) who pay for the site’s cleanup. For the remaining 30 percent of sites, either the EPA cannot locate any PRPs or the PRPs cannot afford to pay for cleanup (Ramseur, Reisch, and McCarthy, 2008). Cleanup at these “orphaned” sites are paid out of the Hazardous Substance Superfund Trust Fund (Superfund). Since the expiration of three excise and one income tax which originally funded Superfund, it is now paid for out of general revenues.\(^{22}\)

The president’s 2014 budget proposal would reinstate all four Superfund taxes for the years

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\(^{22}\)See Probst et al. (1995) for more detail on the Superfund program in general and CBO (2011) for reform options.
2014 through 2023 (Treasury, 2013). Two of the excise taxes would not apply to the energy industry while the income tax would apply to all industries. The only tax of specific relevance to the energy industry is the remaining excise tax, a 9.7 cent per barrel excise tax on domestic crude and on imported petroleum products.

The key question is how polluted site cleanup should be funded. Currently it is paid for out of the general revenue. The proposal would instead use new excise taxes. But polluted site cleanup faces the same tax neutrality issues as oil spills. I therefore propose the same solutions discussed in detail under the Oil Spill Liability Trust Fund and for the same reasons. The law should impose full civil liability for small amounts of pollution. And it should either require firms to purchase excess liability insurance or impose an actuarially fair tax on activities with the possibility for catastrophic pollution that would exceed the firm’s ability to pay. Thus cleanup would be funded either by insurance payouts or an actuarially fair tax.

However, the Superfund excise tax and Oil Spill Liability Trust Fund have similar problems concerning the actuarial fairness of the taxes. The Superfund excise tax is paid by all firms who produce or import petroleum and at the same rate regardless of the care taken by any firm to avoid polluting or the firm’s risk of defaulting on cleanup costs. And it creates a moral hazard for small firms with a high risk of default which does not internalize the cost of pollution. Therefore, the Superfund excise tax is not actuarially fair.

However, Superfund is less problematic than the Oil Spill Liability Trust Fund in that the excise tax is only used to pay for orphaned sites. Under current law, if PRPs can be identified and are able to pay, then the PRPs pay for cleanup at the site. But the case of orphaned sites whose PRPs cannot be identified complicate the analysis. Knowing the reasons why PRPs cannot be identified in these cases is critical. If the inability to identify any PRPs would also prevent identification of their insurance, then an actuarially fair tax would be more efficient than requiring excess liability insurance.

2.2.7 Dual Capacity Rules

The US taxes domestic corporations on the income they earn in foreign countries. However, since the host country can also impose income taxes on the income of corporations earned in that country, this can lead to double taxation of that income. To avoid double taxation, the US tax code allows firms to credit certain foreign levies against their US tax liability. A foreign levy is creditable against the firm’s US tax liability if it is compulsory and is not compensation
by the firm to the host nation for a specific economic benefit. A “dual-capacity taxpayer” is a taxpayer who is subject to a levy by a foreign country that also receives a specific economic benefit from that country.

The tax code allows taxpayers to choose between two methods to determine the portion of the levy paid by the taxpayer that is compulsory and creditable, and the portion that is compensation for a specific economic benefit and deductible. Under the facts and circumstances method, a levy is creditable to the extent that the taxpayer is able to prove that portion of the levy is not paid as compensation for specific economic benefits. Under the safe harbor method, if the host country has a generally imposed income tax, the taxpayer may credit an amount equal to the tax payment that would result from application of the host country’s generally imposed income tax (JCT, 2012). In either case, the foreign tax credit is limited to a taxpayer’s US tax liability on its foreign source income (JCT, 2012).

The president’s 2014 budget proposal would eliminate the current safe harbor and facts and circumstances methods for determining the fraction of a levy that is creditable (Treasury, 2013). Under the new rules, dual capacity taxpayers would be able to treat as creditable the portion of a foreign levy that does not exceed the foreign levy that the taxpayer would pay if it were not a dual-capacity taxpayer (Treasury, 2013). In effect, dual capacity companies would only be able to credit an amount equal to the host nation’s general corporate tax rate applicable to other industries (Pirog, 2012). This is similar to simply forcing firms to choose the safe harbor method. In addition, the special limit for oil and gas income tax credits would be removed and it would instead be treated as its own separate limitation category (Treasury, 2013).

If US dual capacity firms operating outside the US are able to use creditable royalty payments to reduce their tax rate below that faced by other US based firms operating outside the US, who have to pay for economic benefits through deductible but not creditable expenses, then removing these credits enhances the neutrality of the tax code. However, it is unclear that simply forcing all firms to credit taxes using the general corporate tax rate separates the taxes that are true

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23  Treasury Regulation section 1.901-2(a)(2)(i).
25  Treasury Regulation section 1.901-2A(c).
26  These rules were designed because of concerns that income taxes imposed on US oil companies by foreign governments were not income taxes but disguised royalties, which are normally deductible but not creditable (JCT, 2012).
27  Treasury Regulation section 1.901-2A(c)(2)(i).
28  JCT (2012) explains how two additional rules also apply. The credit is restricted by the category of income, generally referred to as “separate limitation category,” so that tax credits from a particular category of income can only offset tax liabilities from that same category of income. In addition to the special limitation categories, credits from oil and gas income taxes may only offset oil and gas income tax liabilities.
income taxes from the taxes that are payments for economic benefits more accurately than the nuanced calculation allowed by the facts and circumstance rule. Indeed, to the extent that it is accurately applied, the facts and circumstances method seems ideal.

Distinct from possible differentials between sectors, another issue is whether foreign source income of US based firms should be taxed at all. There are two major systems states use for the taxation (or non-taxation) of foreign source income. Under a pure residence-based tax system, countries tax their residents (and domestic firms) on their worldwide income. Alternatively, under a territorial tax or source-based tax system, a country only taxes income that is earned within its borders.

Previous literature has not come to a consensus on which system is superior. However, Gravelle (2009) notes that the US is only nominally a residence-based tax system. Under current law, firms only pay taxes on income that is repatriated back to the US and are allowed to defer repatriation indefinitely. This significantly reduces the US tax they pay on foreign source income. In this case, Gravelle (2009) states that a move towards either a more pure residence or territorial tax system would enhance the neutrality of the tax code. Exempting foreign source income entirely and moving to a territorial tax system would encourage the repatriation of income by reducing its tax rate. Alternatively, the tax code could move to a more effective residence system by ending deferral, which would encourage the repatriation of income and also increase the effective tax rate on foreign source income.

The budget uses neither of these methods. By reducing deductions, the effective tax rate on repatriated foreign source income increases but non-repatriated income remains untaxed. This increases the incentive to defer repatriation of foreign source income and decreases the neutrality of the tax code.

2.2.8 Geological and Geophysical Expense Amortization

Geological and geophysical (G&G) expenses are the costs incurred for acquiring data for minerals exploration and include expenditures on geologists, seismic surveys, gravity meter surveys, and magnetic surveys (JCT, 2012). Independent producers and small integrated oil companies may amortize and deduct these costs over two years. Major integrated oil companies are required to amortize the deduction of G&G costs over seven years.

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The president’s 2014 budget proposal would increase the amortization period for independent producers and small integrated oil companies from two years to the same seven years as major integrated oil companies (Treasury, 2013). Major integrated oil companies would be unaffected.

Under a neutral tax system, statutory G&G depreciation would equal economic depreciation and be the same for all firms regardless of organizational form. So it is appropriate that the president’s proposal is to treat independent producers, small integrated oil companies, and large integrated oil companies equally. Bureau of Economic Analysis (2003), hereafter BEA, calculates the geometric economic depreciation rate for petroleum and natural gas mining exploration, shafts, and wells at 0.0751 and lists a service life of 12 years. So the increase in the amortization period for independent producers and small integrated oil companies would move their tax depreciation treatment closer to both economic depreciation and eliminate the difference in tax treatment due to firm organizational form. This change is thus neutrality enhancing.

### 2.2.9 Capital Gains Treatment of Coal Royalties

While in general royalties are taxed as ordinary income, royalty income from the sale of coal mined in the US and held for at least one year can be taxed instead as long-term capital gains (JCT, 2012). The president’s 2014 budget proposal would repeal the capital gains treatment of gains from coal royalties under these circumstances (Treasury, 2013).

There are a variety of considerations that must be taken in dealing with the taxation of ordinary income versus capital gains in a neutral tax system to ensure that income invested and then earned again in a subsequent period is not double taxed. However, in this case these concerns can be safely sidestepped by focusing on the coal itself. Coal and coal royalties are not assets like property or stocks but inventories. Income from the sale of inventories is typically treated as ordinary income, not capital gains. This provision is thus neutrality enhancing.

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30 A summary of the BEA depreciation table as it is relevant to the energy industry is available in Table A1 in the Appendix of Metcalf (2009).

31 Although it brings coal in line with the current law treatment of other inventories, the budget proposal does still deviate somewhat from a neutral system, which would allow inflationary gains to be deducted from income. This point is explained in greater detail in section 2.2.1.
2.2.10 Expensing of Coal Exploration

Exploration is the process of determining if there are sufficient minerals in an area to justify mining. Under current law, taxpayers may elect to expense (immediately deduct) exploration costs in all types of mining, not just coal. Unlike other organizational forms of firms, corporations may only expense 70 percent of the exploration expenses and must amortize over a 60-month period the remaining 30 percent (Treasury, 2013). This deduction is subject to recapture by disallowing percentage depletion deduction on the property for which exploration costs were expensed until “adjusted exploration expenditures” are re-included in income (JCT, 2012).[32]

The president’s 2014 budget proposal would repeal the option to expense and amortize over 60-months exploration and development costs for coal (including lignite) and certain types of oil shale (Treasury, 2013). The costs would instead be capitalized and recovered through depreciation or depletion deductions, as appropriate (Treasury, 2013). Other forms of mining would retain the option to expense and amortize exploration costs.

Under a neutral tax system, a taxpayer would be allowed to deduct capital costs based on the economic rate of depreciation. Exploration costs for a mine that is found to have insufficient quantity or quality of ore to justify mining should be immediately expensed since they will provide no future benefit. However, for a productive mine, they should be deducted at their economic depreciation rate. As was stated before, BEA (2003) calculates the geometric economic depreciation rate for petroleum and natural gas mining exploration, shafts, and wells at 0.0751 and a service life of 12 years, a longer lifetime than the 60-month amortization allowed now. Retaining the deduction for other forms of mining would make the tax system less neutral in regards to which type of mining to invest in but would make the system more neutral for the choice of what type of capital to employ in coal mining.

3 A New Model of Energy Taxation

In this section, I describe my new general equilibrium model of the United States economy. In section 3.1 I review previous literature on modeling energy policy with an emphasis on differences between the literature and my model. Then in section 3.2 I present the details

[32] Adjusted exploration expenditures are the amounts for which the taxpayer claimed an exploration deduction that would have been included in the basis of the property reduced by the excess of the percentage depletion over the depletion allowable had the expenses been capitalized instead (JCT, 2012).
of my general equilibrium model: the equations used to define the supply and demand of commodities, the data used to parametrize these equations, and other assumptions.

3.1 Literature Review

There are two general classes of models in the energy taxation literature: partial equilibrium (PE) and computable general equilibrium (CGE) models.\textsuperscript{33} PE models focus on resource supply decisions by firms and take a large number of different approaches. These approaches include neoclassical (Dasgupta, Heal, and Stiglitz, 1981; Hotelling, 1931), contingent claims (Blake and Roberts, 2006; Lund, 1992), scenario (Hogan and Goldsworthy, 2010; Kemp, 1987), decline curve (Peaceman, 1977), and reservoir simulation models (Adelman, 1973).

Although the different methods are able to examine many issues far better than the model developed in this paper, the critical issue for energy tax modeling is that these methods determine an elasticity of energy resource supply. It is this elasticity which determines the existence of resource rents, and thus makes taxing the income earned by resources less distortionary than other sources of revenue. The model in this paper contains such an elasticity parameter and therefore can determine the impact of a given level of resource rents. Despite their advantages, PE models are, by construction, unable to capture the effects of resource taxes on the entire economy. However, these deficiencies are not shared by the second approach, CGE models of energy taxation.\textsuperscript{34}

Although broadly similar to each other, CGE models differ in their treatment of key details. Paltsev et al. (2005) and Babiker et al. (2008) examined climate change policies using CGE models with an exogenously supplied energy resource. And although Goulder and Hafstead (2013) does not explicitly feature an energy resource, in that model total factor productivity for fossil fuel extraction decreases with cumulative extraction. These specifications are able to address intertemporal issues. However, because the resource is exogenously supplied or only interacts with total factor productivity, these models are not able to consider the impact of economic rents for the energy resource. By contrast, Jorgenson and Yun (2001) and Wilcoxen (1988) have no energy resource at all, but these models do have flexible substitution. They feature translog producer cost functions and consumer expenditure functions whose parameters

\textsuperscript{33}See Lund (2009) or Smith (2012) for comprehensive reviews of the literature on modeling energy taxation.

\textsuperscript{34}A rich literature of non-energy focused CGE models exists but they are typically designed to model fundamental tax reform and thus lack any details unique to the energy sector (Altig et al., 2001; Fullerton and Rogers, 1993; Zodrow and Diamond, 2013).
are estimated with regression analysis.

The model I construct combines the advantages of the CGE and PE literatures. Specifically, input substitution is modeled following Jorgenson and Yun (2001) and Wilcoxen (1988) but with an energy resource component broadly similar to that of Babiker et al. (2008). However, the energy resource in my model is not exogenously supplied; it instead has a simple constant elasticity supply function that reflects a reduced form representation of the effects analyzed in the partial equilibrium literature.

3.2 Model Description

3.2.1 Model Overview

Overall, the model is a 22 sector steady-state CGE model of the US economy. The model features flexible substitution across both production inputs and consumer goods and also endogenous resource supply. These features combine the advantages of the CGE and PE methods of energy tax analysis and allows the model to incorporate the three main efficiency effects of energy taxation. In this section, I summarize the most important features of the model including the baseline parameter values, the translog cost and expenditure functions, and the modeling of taxation. The remaining details are presented in appendixes A and B.

In the model, the cost function for an industry (e.g., manufacturing, health care, and oil and gas extraction) relates the cost of producing the industry’s output to the cost of the industry’s inputs. These inputs are capital, labor, and all the outputs of the industry cost functions. The model utilizes a translog cost function for each industry, following Jorgenson and Yun (2001) and Wilcoxen (1988). Although the functional form of the translog cost function is quite complex, its key features can be described simply: it allows different degrees of substitution between all inputs and it also also technological progress to change total factor productivity and the relative importance of particular inputs over time. Moreover, the parameters of the cost function are estimated separately for each of the 22 industries and for households. All industries are assumed to be perfectly competitive with constant returns to scale, which allows the determination of output price from firm costs.

The relationships between the various parts of the model are summarized in Figure 1. Purchases of goods are made by a government sector, a representative household, the industries, and the rest of the world through imports and exports. Exports are also isocelastically demanded. Conversely, the demand for imports is determined by a constant elasticity of substitution cost
or expenditure function between domestic and imported inputs.

Standard assumptions are made for the supply of capital and labor and the demand for goods. Capital, labor, and the energy resource are assumed to be perfectly mobile between sectors and in the aggregate have isoelastic supply functions. There are no supplier price differentials across sectors for capital or the energy resource but, following Wilcoxen (1988), post-tax wage differentials across sectors are fixed at the ratios that occur in the data.

I perform a series of regressions to estimate the values of the parameters that define the cost functions. Regression estimation of cost function parameters has important advantages over calibrating the model to values taken from a single year. In particular, calibrated parameter values are sensitive to the idiosyncratic conditions of the year of calibration. By contrast, my regression parameters are determined from five decades of data. However, endogeneity is an issue for the regressions since prices, a right hand side variable, are dependent on cost shares, a left hand side variable. Additionally, since the cost shares of all the inputs must sum to one, the error terms of the regressions are correlated. Both of these problems are solved by performing the regressions using iterated three-stage least squares.

The data used in this regression and subsequent model simulations come from several sources. The first is a system of US national accounts covering the years 1960 to 2005 compiled by Jorgenson (2007). These data include the quantity and price of output produced by all industries and all inputs purchased by all industries. Additional data come from the BEA (Bureau of Economic Analysis) Tables of the Use of Commodities by Industries for 1997-2010.

Note that this assumption is made implicitly in any model that aggregates all workers into a single type of labor.
and the BEA Gross Output Price Index for 1987-2010. The older Jorgenson (2007) data are converted to the same industrial classification system as the BEA data using the 1997 Economic Census’s Bridge between NAICS (North American Industrial Classification System) and SIC (Standard Industrial Classification).

In order to determine the economic effects of the president’s budget proposal, I compare two tax regimes. The first is current law, which includes a tax on capital, a tax on labor, a tax on energy reserves, and production taxes on output. In the second tax regime, the energy portions of the president’s fiscal year 2014 budget proposal are implemented, raising tax rates on fossil fuel producers. In addition, capital tax rates are lowered uniformly on all sectors under the second regime. The rate of this capital tax decrease is chosen in order to make the budget proposal regime revenue neutral with current law.

3.2.2 Model Parameters

The values used for the model parameters have one of three sources: regression analysis, previous literature, or raw data. The cost and expenditure function parameters are estimated by a series of regressions. These regressions are described in section 3.2.3.2 and the parameter values they generate are listed in appendix D. By contrast, literature and data parameters are taken from scholarly literature or my estimates from raw data, respectively. These literature or data parameters and their sources are described in this section. Table 2 lists the elasticity and tax parameters that define the responsiveness of capital, labor, resources, imports, and exports to price changes.

A few of the parameters in Table 2 need additional explanation. The first is the Armington elasticity of substitution. I assume a world market for energy products exists because previous literature has found high substitutability of imported and domestic fossil fuels (Balistreri, Al-Qahtani, and Dahl, 2010). Therefore, the model uses a higher Armington elasticity of substitution for fossil fuel production than for other sectors.

The second parameter of note is the elasticity of substitution between KLEM output and the energy resource. This parameter that has not been estimated in the literature. I use as a baseline the value 4, which equals the Armington elasticity of substitution for the cost equation that nests it. However, because of the uncertainty in this parameter’s value, I conduct a sensitivity test using an alternative value for this parameter in section 4.

The third noteworthy parameter is the elasticity of energy resource supply. Varying this
Table 2: Selected Parameters and their Values in the Baseline Specification

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_{\text{capital}}$</td>
<td>Elasticity of capital supply with respect to capital rental rate</td>
<td>0.5</td>
<td>Gunning, Diamond, and Zodrow (2008)</td>
</tr>
<tr>
<td>$\theta_{\text{labor}}$</td>
<td>Elasticity of labor supply with respect to wage rate</td>
<td>0.2</td>
<td>McClelland and Mok (2012)</td>
</tr>
<tr>
<td>$\theta_{\text{resources}}$</td>
<td>Elasticity of resource supply with respect to resource price</td>
<td>0.5</td>
<td>See section 3.2.2</td>
</tr>
<tr>
<td>$\theta_{\text{Arm}}$</td>
<td>Armington elasticity of substitution between domestic and imported fossil fuels</td>
<td>23</td>
<td>Balistreri, Al-Qahtani, and Dahl (2010)</td>
</tr>
<tr>
<td>$\theta_{\text{Arm}}$</td>
<td>Armington elasticity of substitution between domestic and imported goods for goods other than fossil fuels</td>
<td>4</td>
<td>Rutherford and Paltsev (2000)</td>
</tr>
<tr>
<td>$\theta_{\text{export}}$</td>
<td>Own price elasticity of export demand</td>
<td>-1</td>
<td>Senhadji and Montenegro (1999)</td>
</tr>
<tr>
<td>$\theta_{r}$</td>
<td>Elasticity of substitution between resource and KLEM</td>
<td>4</td>
<td>See section 3.2.2</td>
</tr>
<tr>
<td>$\tau_{\text{capital}}$</td>
<td>Effective tax rate on capital</td>
<td>Varies</td>
<td>See section 3.2.4</td>
</tr>
<tr>
<td>$\tau_{\text{labor}}$</td>
<td>Effective tax rate on labor</td>
<td>0.316</td>
<td>CBO (2005)</td>
</tr>
<tr>
<td>$\tau_{\text{resources}}$</td>
<td>Effective tax rate on energy resource</td>
<td>Varies</td>
<td>See section 3.2.4</td>
</tr>
<tr>
<td>$\tau_{\text{production}}$</td>
<td>Effective tax rate on production</td>
<td>Varies</td>
<td>See section 3.2.4</td>
</tr>
</tbody>
</table>

Notes: (1) Fossil fuel producing sectors are oil and gas extraction, petroleum and coal products manufacturing, and pipeline transportation.

elasticity determines the responsiveness of resource supply to changes in economic rents. A value of zero indicates that changes in rents do not affect resource supply. A value of 0.5 is the same as the elasticity for capital, and indicates that the resource has the same responsiveness to changes in rents as capital does to changes in price. Mohn (2010) estimates a price elasticity of over 0.9 for oil supply so a high value of 1.0 is used. In the sensitivity analysis, this parameter is varied from 0.1 to 1.0 to examine the importance of resource rents.

3.2.3 Firm Cost and Consumer Expenditure Functions

3.2.3.1 Functional Forms

This section details the firm cost and consumer expenditure functions that are the source of the model’s flexible substitution. Both consumer expenditure and firm cost functions have the same general form, so only firm costs function will be mentioned in areas where they are the same and any differences will be explicitly pointed out.

In the model, there is not just one single cost function for an entire industry but, following Jorgenson and Yun (2001) and Wilcoxen (1988), production is in each industry characterized by a series of nested cost functions, each with the translog form. The tier structure used to nest the cost functions for each industry is shown in the tree in Figure 2.

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Nesting the cost functions is necessary to reduce the quantity of parameters to be estimated to a manageable number. Nesting reduces parameters by limiting the number of inputs at each node of production and increasing the number of nodes since the number of parameters at a node is of order $N^2$. 

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Figure 2: Tiers for the Translog Cost Function for Firm Production

Final domestic output of industry \( x \) (KLEM\( _{x} \))

\( K_x \) \( L_x \) \( E_x \) \( M_x \)

\( 211 \) \( 22 \) \( 324 \) \( 486 \)

\( 11 \) \( 21 \) \( 31 \) \( 61 \)

\( 62 \) \( 71 \) \( 72 \) \( 51 \)

\( 55 \) \( 56 \) \( 52 \) \( 54 \)

\( 81 \)

\( 42 \) \( 44 \) \( 48 \)

Notes: K is capital, L is labor, and N is non-competing imports. KLEM\( _{x} \) is the top tier output for the translog cost function for industry \( x \) but it is not final composite output good \( x \). See Appendix B.3 for details on how KLEM is combined with the energy resource or imported goods to produce the composite good. Numbers give the NAICS code of the respective sector’s output. All other letters are the names of aggregate outputs.

An aggregate output and its components inputs will be called a “node” of the structure. The top translog node has each sector’s KLEM output created from capital (K), labor (L), energy (E), and materials (M). The KLEM output is the sector’s domestic output, e.g., KLEM for the manufacturing sector is domestic manufacturing output\[^{37} \] Lower nodes are aggregates of particular energy and material inputs\[^{38} \] For example, the aggregate output MO is made from the inputs MOT, input 23 (construction), and input 53 (real estate and rental and leasing). All aggregate outputs are also used as inputs for the next higher stage of the production process. For example, MOT is itself also an aggregate output made from inputs 42 (wholesale trade), 44 (retail trade), and 48 (transportation and warehousing). At the lowest level, the inputs used are capital, labor, the 22 sector final composite outputs. Note that the prices of the final composite outputs are the same across all industries at a particular time but the prices of capital, labor, and aggregate inputs like energy will vary across industries in the same time period.

For each aggregate output (node) \( o \) and each industry \( x \), the translog cost function is

\[
\ln(c_{xot}) = \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \beta_{xij}^{\text{substitution}} \ln(p_{xit}) \ln(p_{xjt}) + \sum_{i=1}^{N} \beta_{x1i}^{\text{share constant}} \ln(p_{x1t}) + \sum_{i=1}^{N} \beta_{x1i}^{\text{share trend}} \ln(p_{x1t}) t + \beta_{x0}^{\text{cost trend}} t + \beta_{x0}^{\text{cost constant}}
\]

where \( \ln(c_{xot}) \), the log of the cost of producing output \( o \) for industry \( x \) at time \( t \), is a function of the log of the input prices \( \ln(p_{xit}) \) of the \( N \) inputs\[^{39} \] \( \ln(p_{x1t}) \) is the log of the price of input

\[^{37} \] For industries that do not produce fossil fuels, KLEM cost is exactly the domestic cost. However, for fossil fuel producing industries, KLEM must be combined with the energy resource to produce the domestic good. See Figure 3 of appendix B.3 for addition details.

\[^{38} \] The KLEM output is not the final output used by consumers or firms. Appendix B.3 details how KLEM is combined with the energy resource and imports to get the final composite output.

\[^{39} \] The value of \( N \), the number of inputs used to make an output, ranges from one to four and is defined for
i at time t to industry x and t is measured in years. The variables $\beta_{xij}^{\text{substitution}}$, $\beta_{xi}^{\text{share constant}}$, $\beta_{xi}^{\text{share trend}}$, $\beta_{xo}^{\text{cost trend}}$, and $\beta_{xo}^{\text{cost constant}}$ for the inputs i and j are the parameters to be estimated at this node by the regression.

Intuitively, $\beta_{xij}^{\text{substitution}}$ defines how use of input i responds to changes in the price of input j for industry x. The variable $\beta_{xi}^{\text{share constant}}$ is an intercept that gives the value share of input i for industry x at this node when time and all log input prices are zero. The variable $\beta_{xi}^{\text{share trend}}$ defines how much the value share of input i changes in one year for industry x if input prices do not change. The variable $\beta_{xo}^{\text{cost trend}}$ is a productivity parameter that defines how much the cost of output changes over time for industry x. The variable $\beta_{xo}^{\text{cost constant}}$ is the constant term of the cost function. It is the cost of output at time 0 when all input prices are 1. Because the cost of all outputs except for KLEM is unobservable, I cannot estimate the parameters $\beta_{xo}^{\text{cost trend}}$ or $\beta_{xo}^{\text{cost constant}}$ when $o \neq \text{KLEM}$. I therefore constrain them to be 0 when $o \neq \text{KLEM}$. However, these parameters are not independently identified from $\beta_{xo}^{\text{share trend}}$ and $\beta_{xo}^{\text{share constant}}$ in the next higher node of the tier structure, so my assumption does not affect results.

The household consumption expenditure function follows the same general format as the firm cost functions: a translog expenditure function that is nested into tiers. However, there are two differences. First, the following goods are not bought by consumers: 23 (construction), 212 (mining - except oil and gas), 55 (management of companies and enterprises), 211 (oil and gas extraction), 213 (mining support activities), capital, and labor. And because the cost of the final consumption good is not observed, I cannot estimate the parameters $\beta_{xo}^{\text{cost trend}}$ or $\beta_{xo}^{\text{cost constant}}$ for consumers even at node KLEM. I therefore constrain them to be 0 for consumers at all nodes. However, this assumption also does not affect results because these parameters correspond to a positive affine transformation of the utility function and thus do not impact preference orderings.

### 3.2.3.2 Regressions for Cost and Expenditure Function Parametrization

In this section, I estimate the parameter values of Equation 1 for each output and industry through a series of regressions. The preferred specification of the regression is iterated three-stage least squares with one-year lagged prices used as instruments. Appendix B.2.1 presents additional details of the regressions and their exact functional forms. Iterated three-stage least
squares is the preferred regression specification because it accounts for both endogeneity of prices and cost shares and correlation between cost shares. However, the use of instrumental variables can introduce new problems if the instruments are weak. Therefore, I test the overidentifying restrictions to see to what extent the instruments are weak. In order to determine the effect of the instruments on the model, I also estimate two alternative specifications and perform a Monte Carlo simulation. These sensitivity tests indicate that model results are not significantly affected by the choice of instruments or the fact that some excluded instruments are weakly correlated with the included endogenous variables.

Table 3 describes the regression results. Due to the extremely large number of parameters, Table 3 presents the mean and standard deviation of regression $R^2$ statistics instead of all parameter estimates and their associated standard errors. For most commodities, the $R^2$ values of the cost share equation are presented because no cost equation exists. However, the $R^2$ is calculated differently for commodity KLEM than for the others. For commodity KLEM, the $R^2$ values from the cost equation are presented because no cost share equation exists. The average $R^2$ value is 0.993 for KLEM. Because KLEM is essentially the final domestic cost for a sector, this high $R^2$ shows that the predictive power of the system of cost functions as a whole is quite high.

I test the validity of the instrumental variable specification using both underidentification and weak identification tests. Results of these tests are presented in Table 4. A Lagrange multiplier version of the Anderson canonical correlation test statistic is calculated in order to test for underidentification (Anderson, 1951). The p-value of this test statistic is reported in column 1 of Table 4. Except for output KLEM, on average all regressions reject underidentification at either the 1 or 5 percent level of statistical significance. However, underidentification for commodity KLEM cannot be rejected at even the 10 percent level. In addition, there is high variance in some of the p-values. Appendix E indicates that these p-values are very high for consumers but very low for industries. Therefore underidentification may be a problem for the

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40 Full regression parameter estimates are presented in appendix D. Full summary statistics are presented in appendix E.

41 Note that the typical method of calculating the total sum of squares, the sum of the regression and residual sum of squares, is incorrect because instrumental variables are used. Instead, $R^2 = \rho_{Y,\hat{Y}}^2$ where $Y$ and $\hat{Y}$ are the actual and predicted values of the dependent variable and $\rho_{Y,\hat{Y}}$ is the correlation coefficient between them.

42 As explained in Baum, Schaffer, and Stillman (2002), “The test is essentially the test of the rank of a matrix: under the null hypothesis that the equation is underidentified, the matrix of reduced form coefficients on the L1 excluded instruments has rank=K1-1 where K1=number of endogenous regressors. Under the null, the statistic is distributed as chi-squared with degrees of freedom=(L1-K1+1). A rejection of the null indicates that the matrix is full column rank, i.e., the model is identified.”
Table 3: Regression $R^2$ Statistics

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>0.480</td>
<td>0.276</td>
</tr>
<tr>
<td>21</td>
<td>0.253</td>
<td>0.254</td>
</tr>
<tr>
<td>211</td>
<td>0.166</td>
<td>0.190</td>
</tr>
<tr>
<td>22</td>
<td>0.579</td>
<td>0.246</td>
</tr>
<tr>
<td>23</td>
<td>0.635</td>
<td>0.220</td>
</tr>
<tr>
<td>31</td>
<td>0.486</td>
<td>0.239</td>
</tr>
<tr>
<td>324</td>
<td>0.594</td>
<td>0.227</td>
</tr>
<tr>
<td>42</td>
<td>0.388</td>
<td>0.305</td>
</tr>
<tr>
<td>44</td>
<td>0.383</td>
<td>0.326</td>
</tr>
<tr>
<td>48</td>
<td>0.335</td>
<td>0.309</td>
</tr>
<tr>
<td>486</td>
<td>0.705</td>
<td>0.268</td>
</tr>
<tr>
<td>51</td>
<td>0.483</td>
<td>0.227</td>
</tr>
<tr>
<td>52</td>
<td>0.370</td>
<td>0.273</td>
</tr>
<tr>
<td>53</td>
<td>0.573</td>
<td>0.329</td>
</tr>
<tr>
<td>54</td>
<td>0.401</td>
<td>0.274</td>
</tr>
<tr>
<td>55</td>
<td>0.266</td>
<td>0.204</td>
</tr>
<tr>
<td>56</td>
<td>0.364</td>
<td>0.310</td>
</tr>
<tr>
<td>61</td>
<td>0.337</td>
<td>0.246</td>
</tr>
<tr>
<td>62</td>
<td>0.831</td>
<td>0.162</td>
</tr>
<tr>
<td>71</td>
<td>0.379</td>
<td>0.374</td>
</tr>
<tr>
<td>72</td>
<td>0.836</td>
<td>0.066</td>
</tr>
<tr>
<td>81</td>
<td>0.393</td>
<td>0.258</td>
</tr>
<tr>
<td>E</td>
<td>0.537</td>
<td>0.254</td>
</tr>
<tr>
<td>K</td>
<td>0.410</td>
<td>0.249</td>
</tr>
<tr>
<td>L</td>
<td>0.567</td>
<td>0.159</td>
</tr>
<tr>
<td>M</td>
<td>0.458</td>
<td>0.232</td>
</tr>
<tr>
<td>MM</td>
<td>0.671</td>
<td>0.212</td>
</tr>
<tr>
<td>MO</td>
<td>0.671</td>
<td>0.306</td>
</tr>
<tr>
<td>MOT</td>
<td>0.239</td>
<td>0.247</td>
</tr>
<tr>
<td>MP</td>
<td>0.868</td>
<td>0.126</td>
</tr>
<tr>
<td>MS</td>
<td>0.787</td>
<td>0.185</td>
</tr>
<tr>
<td>MSS</td>
<td>0.544</td>
<td>0.254</td>
</tr>
<tr>
<td>N</td>
<td>0.494</td>
<td>0.198</td>
</tr>
<tr>
<td>KLEM$^1$</td>
<td>0.993</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Notes: (1) For commodity KLEM, the mean and standard deviation of the $R^2$ values from the cost equation are presented because no cost share equation exists. For all other commodities, the mean and standard deviation of the $R^2$ values of the cost share equation are presented and no cost equation exists.
Table 4: Regression Instrumental Variable Statistics

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Under ID P-Value (%)</th>
<th>Weak Stat</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>3.5</td>
<td>4.923</td>
<td>3.5</td>
<td>16.3</td>
<td>4.923</td>
<td>1.047</td>
</tr>
<tr>
<td>M</td>
<td>3.5</td>
<td>7.364</td>
<td>3.5</td>
<td>15.6</td>
<td>7.364</td>
<td>2.754</td>
</tr>
<tr>
<td>MM</td>
<td>3.2</td>
<td>4.113</td>
<td>3.2</td>
<td>14.7</td>
<td>4.113</td>
<td>1.109</td>
</tr>
<tr>
<td>MO</td>
<td>0.1</td>
<td>11.864</td>
<td>0.1</td>
<td>0.3</td>
<td>11.864</td>
<td>3.832</td>
</tr>
<tr>
<td>MOT</td>
<td>2.0</td>
<td>2.025</td>
<td>2.0</td>
<td>3.3</td>
<td>2.025</td>
<td>0.335</td>
</tr>
<tr>
<td>MP</td>
<td>1.6</td>
<td>4.564</td>
<td>1.6</td>
<td>7.4</td>
<td>4.564</td>
<td>0.947</td>
</tr>
<tr>
<td>MS</td>
<td>1.0</td>
<td>2.868</td>
<td>1.0</td>
<td>4.3</td>
<td>2.868</td>
<td>0.532</td>
</tr>
<tr>
<td>MSS</td>
<td>0.2</td>
<td>9.273</td>
<td>0.2</td>
<td>0.9</td>
<td>9.273</td>
<td>1.722</td>
</tr>
<tr>
<td>KLEM</td>
<td>10.9</td>
<td>2.538</td>
<td>10.9</td>
<td>12.2</td>
<td>2.538</td>
<td>3.310</td>
</tr>
</tbody>
</table>

Results for the second tests also suggests that the instruments are weak. For this test, I calculate the Cragg-Donald statistic in column 3 (Cragg and Donald, 1993). Stock and Yogo (2002) calculate a variety of critical values of this test statistic but not for the exact configuration used here: 4 instruments and 4 endogenous regressors. However, for 5 instruments and 3 endogenous regressors, the critical value is 4.30. This is significantly larger than the test statistic for MOT and most importantly, KLEM, suggesting that the instruments may be weak.

However, further investigation shows that weak instruments are not problematic for the model results. Two alternative regression specifications are used to investigate the significance of weak instruments. First, instead of using one-year lagged values of the input prices as instruments, I use two-year lagged values. Second, instrumental variables are dropped completely and instead of iterated three-stage least squares, the regression is performed with seemingly unrelated regressions. The results of the model’s simulation under these alternative specifications are presented in Table 8 of section 4.2. However, these alternative specifications give very similar predictions to the baseline for all economic variables except the implicit social cost of carbon. Additionally, Monte Carlo methods are used to assess the effect of any instability in parameter estimates resulting from weak instruments. Results of this analysis are shown in Table 9 of section 4.2. These specifications show that any such instability does not affect qualitative results and could even decrease the benefits of the budget proposal.

To summarize, the statistics presented here give a positive appraisal of the regression specification. The $R^2$ of the KLEM output equation is nearly 1. Additionally, I find evidence of weak identification but determine that alternative instruments, no instruments at all, and the

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43 This value is for the test based on two-stage least squares bias and a 0.30 maximal bias of instrumental variables relative to ordinary least squares.
instability in parameters results from weak instruments all do not affect qualitative results. Therefore, I conclude that the regression provides robust parameter values to the model.

3.2.4 Taxation

This section describes the tax rates used in the model, both for current law and under the budget proposal. In order to accurately analyze the effect of the budget proposal, the model includes government taxes on capital, labor, energy resources, and production under both current law and the budget proposal. The tax rates for production are determined from empirical data while the tax rate for labor is taken from the literature. By contrast, the rates for capital and resource taxes are determined partly from data and partly from the literature. Under the budget proposal, the tax rate changes for each provision of the proposal are determined by first assigning a base to each provision. The provision’s tax rate change is then calculated by dividing the projected revenue increase from that provision by that base. The effect of the entire budget proposal is calculated by summing the rate changes for each provision for their respective tax base.

3.2.4.1 Current Law Tax Rates

Current law tax rates are calculated using data from a number of sources. The tax rate on labor income is set equal to 31.6 percent following CBO (2005). The production tax rate for each industry’s output is equal to the the AETR of all production taxes on a value of output base calculated as described in appendix [C.2] and presented in appendix [C.3].

The capital tax rate is equal to the sum of the firm and personal-level capital tax rates. The rates for the firm-level capital taxes vary by industry and are taken from the relevant average effective tax rate (AETR) results calculated using the methodology in appendix [C.2]. Due to data limitations, this AETR includes firm level taxes but does not include individual level taxes such as those on capital gains, dividends, or income from pass-through entities. I include the aggregate effect of these taxes by setting all sectors’ personal level capital taxes equal to 12.5 percent. This value causes total firm and personal capital taxes for the entire economy to average 20 percent as found in Mackie (2002). Unfortunately, this method ignores any variation in individual level capital tax rates between sectors. However, in order for individual level capital taxes to lower taxes for fossil fuel production relative to other sectors, individual taxes would need to vary systematically by industry and with negative correlation to the rates calculated in
Table 5: Tax Bases for Provisions of the Budget Proposal

<table>
<thead>
<tr>
<th>Provision and Industry Base</th>
<th>Factor Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>All fossil fuel production¹:</td>
<td></td>
</tr>
<tr>
<td>Repeal the domestic manufacturing deduction for fossil fuels</td>
<td>Capital</td>
</tr>
<tr>
<td>Modify tax rules for dual capacity taxpayers</td>
<td>Capital</td>
</tr>
<tr>
<td>All other fossil fuel specific provisions</td>
<td>Capital</td>
</tr>
<tr>
<td>Petroleum and coal products manufacturing:</td>
<td></td>
</tr>
<tr>
<td>Repeal LIFO inventory accounting for all sectors</td>
<td>Capital</td>
</tr>
<tr>
<td>Reinstate Superfund excise taxes</td>
<td>Output</td>
</tr>
<tr>
<td>Increase Oil Spill Liability Trust Fund financing rate</td>
<td>Output</td>
</tr>
<tr>
<td>Mining:</td>
<td></td>
</tr>
<tr>
<td>Repeal the capital gains treatment of coal royalties</td>
<td>Capital</td>
</tr>
<tr>
<td>Repeal percentage depletion for coal and other hard mineral fossil fuels</td>
<td>Output</td>
</tr>
<tr>
<td>Repeal expensing of coal exploration and development</td>
<td>Capital</td>
</tr>
<tr>
<td>Oil and gas extraction:</td>
<td></td>
</tr>
<tr>
<td>Repeal expensing of intangible drilling costs</td>
<td>Capital</td>
</tr>
<tr>
<td>Repeal percentage depletion for oil and gas</td>
<td>Output</td>
</tr>
<tr>
<td>Increase geological and geophysical amortization period</td>
<td>Capital</td>
</tr>
</tbody>
</table>

Notes: (1) Fossil fuel production is defined as oil and gas extraction, petroleum and coal products manufacturing, and pipeline transportation.

appendix C.3. To reduce the effect of outliers, a ceiling of 35 percent, the maximum statutory federal corporate rate, is set on the current law firm capital tax rates used in the model. The tax rate for the energy resource is based off of the capital tax rate for fossil fuel producers: \( \tau_{\text{resource}} \) is equal to the value of \( \tau_{\text{capital},x} \) where \( x \) = the oil and gas extraction industry.

3.2.4.2 Budget Proposal Tax Rate Increases

In order to model the budget proposal, the provisions of the proposal must be expressed in a method conformable with the model’s variables. This is done by assigning each budget provision to a particular tax base (capital or production) for a particular sector or set of sectors, as shown in Table 5. The tax rate this provision applies to these bases and sectors is calculated by dividing the proposal’s average yearly revenue from JCT (2013) by the 2009 tax base of these sectors. In order to calculate the effect of the budget proposal as a whole, the tax rates implied for each base and each sector are summed over all provisions to provide a cumulative rate for all provisions for that base and sector.

However, LIFO complicates this calculation. The LIFO change includes both a permanent increase in tax rates due to the taxation of future inventory appreciation and also a one-time tax payment from the taxation of current LIFO reserves. In addition, the LIFO change applies

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⁴⁴Since I cannot disprove this possibility, additional results are presented in section 4 using METRs from Mackie (2002) instead of my AETRs.
to all industries, not just fossil fuel extraction. However, the JCT (2013) revenue estimate does not disaggregate all these effects. Therefore instead of using JCT (2013), I calculate the revenue increase of the LIFO inventory change using JCT (2014a)’s estimate of the revenue increase of removing LIFO from 2016–2018, which is equal to the permanent tax rate increase of removing LIFO (JCT, 2014b). Because Przybyla (2011) indicates that 82 percent of LIFO reserves are held by energy companies, I allocate 82 percent of this tax increase to petroleum and coal products manufacturing, and the other 18 percent to all other sectors.

4 Results

In this section, I use the computable general equilibrium model described in section 3.2 to examine the impact of the changes to fossil fuel taxation proposed in the president’s 2014 budget. I calculate how economic variables would change if the proposal were implemented. I find that the budget proposal reduces fossil fuel production and also reduces social welfare before externalities are taken into account. Sensitivity tests show that these results are robust to a variety of changes to the model. The results confirm the importance of general equilibrium modeling, flexible substitution, endogenous energy resource supply, and externalities.

4.1 Baseline Results

Table 6 illustrates the macroeconomic effects of implementing the budget proposal. The economic efficiency of the proposal is first measured using the welfare of the representative household, excluding carbon externalities. Under the budget proposal, household welfare would decrease by 0.50 percent. In addition, other economic variables such as the capital stock, employment, household consumption, domestic output, wages, and the capital rental rate would also all decrease under the budget proposal.

The explanation for the decrease in welfare (excluding externalities) can be traced to these other economic variables. I then follow the changes in these variables back to their original source. The decrease in welfare is caused by the decrease in consumption, which is caused by the decrease in income. The decrease in income is in turn caused by the decrease in capital and labor prices and quantities. The decrease in capital and labor prices also lead to the decrease in quantities supplied. Therefore, the decrease in capital and labor prices are the root cause of all these changes.
Table 6: Macroeconomic Effects of the Budget Proposal under Baseline Assumptions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percent Change in Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welfare</td>
<td>-0.50</td>
</tr>
<tr>
<td>Capital Stock</td>
<td>-0.04</td>
</tr>
<tr>
<td>Employment</td>
<td>-0.01</td>
</tr>
<tr>
<td>Consumption</td>
<td>-0.17</td>
</tr>
<tr>
<td>Output</td>
<td>-0.13</td>
</tr>
<tr>
<td>Capital Rental Rate(^1)</td>
<td>-0.09</td>
</tr>
<tr>
<td>Labor Wage Rate(^1)</td>
<td>-0.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Social Cost of Carbon</th>
<th>Value ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14</td>
</tr>
</tbody>
</table>

Notes: (1) Wage and capital rental rates are the post-tax rates expressed using the price of consumption as a numéraire.

Recall that the three pathways by which energy taxes can lead to efficiency changes are production and consumption, resource rents, and externalities. The baseline results are driven by the first issue, production and consumption inefficiency. The budget proposal decreases the efficiency of the allocation of capital and labor across industries, lowering their productivity, and thus also lowering their price\(^{45}\).

Industry level effects of the budget proposal are similar to the macroeconomic effects. Table 7 presents the effects of the budget proposal on each industry’s output price, the quantity of output, the industry produces, and the capital and labor employed by the industry. In general, all of these variables decrease. In particular, since the proposal increases capital taxes on fossil fuel producing sectors, the capital stock in these sectors falls. The capital stock in oil and gas extraction falls the most, by 7.34. Perhaps surprisingly, the capital and labor employed by these industries decreases far more than their output falls. However, this is because capital and labor are relatively unimportant in these industries. Together capital and labor are only 12% of costs for petroleum and coal products manufacturing and 11% for oil and gas extraction.

The reduction in fossil fuel production leads to the primary benefit of the proposal: a reduction in carbon emissions. I compare the benefits of the reduction in carbon emissions to the cost of reduced household welfare, before carbon emissions are taken into account. I do so by calculating the budget proposal’s implied social cost of carbon: the cost of carbon for which the budget proposal has zero net effect on household welfare. This implied social cost of carbon is equal to the equivalent variation that households would pay to avoid the budget

\(^{45}\)I refer only to productive efficiency and inputs here because the arguments are exactly the same for consumptive efficiency and goods.
Table 7: Industry Level Effects of the Budget Proposal

<table>
<thead>
<tr>
<th>Industry</th>
<th>Percent Change in</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Consumer Price</td>
<td>Output</td>
<td>Stock</td>
<td>Employment</td>
</tr>
<tr>
<td>Accommodation and Food Services</td>
<td>-0.05</td>
<td>-0.09</td>
<td>0.02</td>
<td>-0.07</td>
</tr>
<tr>
<td>Administrative and Waste Management</td>
<td>-0.05</td>
<td>-0.10</td>
<td>0.05</td>
<td>-0.05</td>
</tr>
<tr>
<td>Agriculture, Forestry, Fishing, and Hunting</td>
<td>0.01</td>
<td>-0.06</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>Arts, Entertainment, and Recreation</td>
<td>-0.02</td>
<td>-0.10</td>
<td>-0.06</td>
<td>-0.07</td>
</tr>
<tr>
<td>Construction</td>
<td>0.00</td>
<td>-0.02</td>
<td>-0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Educational Services</td>
<td>-0.05</td>
<td>-0.10</td>
<td>0.01</td>
<td>-0.09</td>
</tr>
<tr>
<td>Finance and Insurance</td>
<td>-0.08</td>
<td>-0.01</td>
<td>0.05</td>
<td>-0.01</td>
</tr>
<tr>
<td>Health Care and Social Assistance</td>
<td>-0.03</td>
<td>-0.13</td>
<td>-0.06</td>
<td>-0.13</td>
</tr>
<tr>
<td>Information</td>
<td>-0.05</td>
<td>-0.01</td>
<td>0.07</td>
<td>-0.01</td>
</tr>
<tr>
<td>Management of Companies and Enterprises</td>
<td>-0.08</td>
<td>0.08</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>-0.03</td>
<td>0.00</td>
<td>0.14</td>
<td>0.03</td>
</tr>
<tr>
<td>Mining</td>
<td>0.20</td>
<td>-0.21</td>
<td>-0.18</td>
<td>-0.22</td>
</tr>
<tr>
<td>Oil and Gas Extraction</td>
<td>0.52</td>
<td>-2.65</td>
<td>-7.34</td>
<td>-14.52</td>
</tr>
<tr>
<td>Other Services</td>
<td>-0.06</td>
<td>-0.07</td>
<td>0.03</td>
<td>-0.07</td>
</tr>
<tr>
<td>Petroleum and Coal Products Manufacturing</td>
<td>0.92</td>
<td>-2.40</td>
<td>-3.61</td>
<td>-6.94</td>
</tr>
<tr>
<td>Pipeline Transportation</td>
<td>0.45</td>
<td>-0.62</td>
<td>-0.77</td>
<td>-0.71</td>
</tr>
<tr>
<td>Professional, Scientific, and Technical Services</td>
<td>-0.03</td>
<td>-0.03</td>
<td>0.03</td>
<td>-0.04</td>
</tr>
<tr>
<td>Real Estate and Rental and Leasing</td>
<td>-0.06</td>
<td>-0.04</td>
<td>0.01</td>
<td>-0.03</td>
</tr>
<tr>
<td>Retail Trade</td>
<td>-0.04</td>
<td>-0.12</td>
<td>0.00</td>
<td>-0.09</td>
</tr>
<tr>
<td>Transportation and Warehousing</td>
<td>0.18</td>
<td>-0.21</td>
<td>-0.12</td>
<td>0.00</td>
</tr>
<tr>
<td>Utilities</td>
<td>0.09</td>
<td>-0.29</td>
<td>-0.18</td>
<td>-0.12</td>
</tr>
<tr>
<td>Wholesale Trade</td>
<td>-0.04</td>
<td>-0.01</td>
<td>0.08</td>
<td>0.02</td>
</tr>
</tbody>
</table>

I find that if the total social cost of carbon from all externalities is $14, the budget proposal gives households the same welfare as under current law. For higher carbon costs, the budget proposal increases household welfare. For lower costs, it reduces welfare. By comparison, the Interagency Working Group on Social Cost of Carbon (2013) lists mean estimates of the marginal social costs of carbon for 2015 ranging from $11 to $52, depending on the discount rate used.

In total, these results highlight the importance of the features of my model relating to general equilibrium modeling, flexible substitution, and externalities. A partial equilibrium model could not determine that the budget proposal reduces household welfare, excluding externalities. Additionally, a model without flexible substitution would not predict the large drop in fossil fuel capital relative to the drop in output. This would lead the model to either overstate the reduction in carbon emissions or understate the efficiency loss from input substitution. And finally, a model without externalities would underestimate the benefits of the proposal. All three play a role in accurately determining the effects of the budget proposal. In the next section, I

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46 See Appendix B.7.1 for an explanation of how the change in carbon emissions is calculated.

47 The social cost of carbon estimated by the Interagency Working Group on Social Cost of Carbon (2013) apparently does not include energy security externalities since this category is not explicitly listed.
perform sensitivity tests and also evaluate the role of the last issue: resource rents.

### 4.2 Sensitivity Tests

I test the robustness of the baseline results presented thus far with a number of alternative model specifications. These alternative specifications change parameters or assumptions from those in the baseline and then examine how results respond. Recall that in the baseline specification, \( \theta_{\text{capital}} = 0.5 \), \( \theta_{\text{labor}} = 0.2 \), \( \theta_{\text{resource}} = 0 \), \( \theta_{r} = 4 \), and \( \theta_{\text{FossilFuelProduction}}^{\text{Arm}} = 23 \). In addition, in the baseline specification the energy resource is separate from capital and the average effective tax rates (AETRs) calculated in appendix C.3 are used for the capital tax rates. Furthermore, the translog cost function parameters are estimated using iterated three-stage least squares with one year lagged prices used as the first-stage instrumental variables. All of these parameters or assumptions are changed in at least one sensitivity test. My results are robust to the removal of any of these assumptions.

Economic variables do not change markedly under the various alternative specifications. Table 8 presents the changes in welfare, capital stock, employment, or consumption caused by the budget proposal under all alternative model specifications. The table also lists the different social costs of carbon necessary for the budget proposal to have zero net effect on household

### Table 8: Macroeconomic Effects of the Budget Proposal Under Alternative Assumptions

<table>
<thead>
<tr>
<th>Parameter Values(^1)</th>
<th>Percent Change in</th>
<th>Social Cost of Carbon ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Welfare(^2)</td>
<td>Capital Stock</td>
</tr>
<tr>
<td>1 Baseline</td>
<td>-0.50</td>
<td>-0.04</td>
</tr>
<tr>
<td>2 ( \theta_{\text{capital}} = 1 )</td>
<td>-0.25</td>
<td>-0.09</td>
</tr>
<tr>
<td>3 ( \theta_{\text{capital}} = 0.2 )</td>
<td>-0.40</td>
<td>-0.02</td>
</tr>
<tr>
<td>4 ( \theta_{\text{labor}} = 0.3 )</td>
<td>-1.03</td>
<td>-0.05</td>
</tr>
<tr>
<td>5 ( \theta_{\text{labor}} = 0.1 )</td>
<td>-0.28</td>
<td>-0.04</td>
</tr>
<tr>
<td>6 ( \theta_{\text{resource}} = 1 )</td>
<td>-0.54</td>
<td>-0.05</td>
</tr>
<tr>
<td>7 ( \theta_{\text{resource}} = 0.1 )</td>
<td>-0.46</td>
<td>-0.04</td>
</tr>
<tr>
<td>8 ( \theta_{r} = 0.1 )</td>
<td>-0.63</td>
<td>-0.06</td>
</tr>
<tr>
<td>9 ( \theta_{\text{capital}} = 1, \theta_{\text{labor}} = 0.3, \theta_{\text{resource}} = 1 )</td>
<td>-0.36</td>
<td>-0.10</td>
</tr>
<tr>
<td>10 ( \theta_{\text{capital}} = 0.2, \theta_{\text{labor}} = 0.1, \theta_{\text{resource}} = 0.1 )</td>
<td>-0.85</td>
<td>-0.01</td>
</tr>
<tr>
<td>11 ( \theta_{\text{FossilFuelProduction}}^{\text{Arm}} = 4 )</td>
<td>-0.24</td>
<td>0.00</td>
</tr>
<tr>
<td>12 Energy resource treated as capital</td>
<td>-0.76</td>
<td>-0.09</td>
</tr>
<tr>
<td>13 Mackie (2002) capital METRs</td>
<td>-0.70</td>
<td>-0.05</td>
</tr>
<tr>
<td>14 Regression: 2 period lags for IV</td>
<td>-0.25</td>
<td>-0.03</td>
</tr>
<tr>
<td>15 Regression: no instruments</td>
<td>-1.24</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

Notes: (1) Except for the changes explicitly noted under “parameter values,” all specifications use the same parameter values and methods as the baseline (specification 1).
(2) Because household utility can be negative, percentage change values can be misleading. Therefore I present the absolute percent change so that positive percents represent increases in welfare while negative numbers represent decreases in welfare.
welfare. Specification 1 is the baseline, while specifications 2 through 7 vary the price elasticities of supply for capital, labor, and energy resources. However, under these specifications all variables retain the same sign as the baseline and have similar magnitudes.

Specifications 6 and 7 are especially noteworthy because they deal with the elasticity of energy resource supply. Recall that energy resource supply is better modeled by partial equilibrium models than general equilibrium models. However, these specifications have very similar results, which indicates that the exact value used for the elasticity of the energy resource is not important. This finding suggests that the advantage of partial equilibrium models in this area may not be important for final results.

Other changes are also considered. Specification 8 changes the elasticity of technical substitution for the energy resource, while specifications 9 and 10 change multiple elasticities at once to all be high or low. However, again, results are similar to the baseline. Specifications 11 through 15 consider more fundamental changes that have larger impacts on results than varying elasticity parameters. In specification 11, I reduce the Armington elasticity substitution of imported and domestic fossil fuels to 4 (from 23 in the baseline simulation). This greatly reduces the welfare loss of the proposal and the social cost of carbon necessary to justify it, while also providing the one change in sign of any variable: the budget proposal now has no effect on the aggregate capital stock. This indicates that import assumptions significantly impact results: if importation of fossil fuels were as difficult as the importation of a typical good (i.e. an elasticity of 4 instead of 23), then raising taxes on fossil fuels would be less inefficient. It also shows that models that do not allow for substitution toward imported fossil fuels, such as partial equilibrium models or CGE models that assume inelastic import demand, underestimate the negative effects of energy taxes.

One of the primary goals of this paper has been to incorporate endogenous resource supply into a general equilibrium model. The importance of endogenous resource supply can be evaluated by considering a specification without it, specifically, by including the energy resource as part of the capital stock instead of as a separate factor of production. This is considered in specification 12. Compared to the baseline, the effects of the proposal on the social cost of carbon increase to some of the highest levels of any specification. This indicates that including the energy resource as a separate input meaningfully impacts results and that models without an energy resource would overestimate the efficiency costs of the budget proposal. In addition, comparison of this specification to specifications 6 and 7 show that including an energy resource
has a large effect on the carbon price necessary to justify the proposal but exactly how the model includes the energy resource is much less important.

In specification 13, I consider model sensitivity to alternative tax rates. Although appendix C.2 mentions a number of advantages the AETR has over the METR in this situation, the METR is still the standard method of measuring tax rates. In order to examine if results are driven by the use of AETRs, specification 13 uses the capital METR calculated by Mackie (2002) instead of my calculated capital AETRs. However, the effects of the proposal under this specification are still negative and similar in size to the baseline.

Additionally, I consider several alternative specifications of the regression used to parametrize the translog consumer expenditure and firm cost functions. In the baseline, iterated three-stage least squares was used to parametrize the cost function. Intuitively, three-stage least squares can be thought of as instrumental variables (two-stage least squares or IV) followed by seemingly unrelated regressions (SUR). The ideal sensitivity test would be to perform this regression first with only the IV portion of the regression, then with only the SUR portion, and finally by ordinary least squares. However, it is not possible to perform the regression without the SUR portion. Recall that in order to ensure that the translog cost function I estimate is a legitimate cost function, I must impose cross equation restrictions on the parameter values. Therefore, it is not possible to remove the SUR part of the regression without relaxing these restrictions.

Instead, I perform sensitivity tests only on the IV portion of the regression. This is done in specifications 14 and 15. In the baseline specification, the instruments used for the first-stage are the one year lagged values of the input prices. In specification 14, the 2 year lagged values are used instead. In specification 15, no instruments are used at all. In both cases the proposal has a negative impact on all economic variables. Recall that section 3.2.3.2 showed evidence that the baseline specification may be using weak instruments. These sensitivity tests show that the results on welfare, capital stock, employment, consumption, and the social cost of carbon are not driven by the choice of instruments.

In addition to these sensitivity tests, I examine the translog cost function’s parameters as a whole as well. Varying individual parameter values is an effective method of determining the sensitivity of model predictions to a small set of parameters. Unfortunately, this method cannot

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48 For brevity, I refer only to the firm cost function as it is treated identically to the consumer expenditure function in these tests.

49 See appendix B.2.2 for a list of what these restrictions are and how they are imposed.
Table 9: Macroeconomic Effects of the Budget Proposal in the Monte Carlo Simulation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percentile of Percent Change in Variable</th>
<th>5%</th>
<th>50%</th>
<th>95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welfare</td>
<td></td>
<td>-0.52</td>
<td>-0.43</td>
<td>-0.27</td>
</tr>
<tr>
<td>Capital Stock</td>
<td></td>
<td>-0.05</td>
<td>-0.04</td>
<td>-0.04</td>
</tr>
<tr>
<td>Employment</td>
<td></td>
<td>-0.01</td>
<td>-0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>Consumption</td>
<td></td>
<td>-0.18</td>
<td>-0.16</td>
<td>-0.11</td>
</tr>
<tr>
<td>Output</td>
<td></td>
<td>-0.13</td>
<td>-0.13</td>
<td>-0.11</td>
</tr>
<tr>
<td>Capital Rental Rate</td>
<td></td>
<td>-0.10</td>
<td>-0.09</td>
<td>-0.07</td>
</tr>
<tr>
<td>Labor Wage Rate</td>
<td></td>
<td>-0.06</td>
<td>-0.06</td>
<td>-0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Percentile of Variable</th>
<th>5%</th>
<th>50%</th>
<th>95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social Cost of Carbon</td>
<td></td>
<td>19</td>
<td>15</td>
<td>12</td>
</tr>
</tbody>
</table>

Notes: (1) Wage and capital rental rates are the post-tax rates expressed using the price of consumption as a numéraire.

be used to evaluate the entire translog cost function because of the large number of parameters involved. However, Monte Carlo methods can handle large numbers of parameters as long as their distribution is known. I use a Monte Carlo simulation to test the robustness of results to the estimated parameters of the translog cost and expenditure functions. New parameter values $\beta$ are drawn from the multivariate distribution

$$\beta \sim \mathcal{N}(\beta^*, \Sigma^*)$$

(2)

where $\beta^*$ and $\Sigma^*$ are from the seemingly unrelated regressions portion of the iterated three-stage least squares regression. $\beta^*$ is the vector of estimated parameter values and $\Sigma^*$ is the estimated variance-covariance matrix for the parameter estimates. 20 draws from this distribution are taken for each variable. The cost function parameters resulting from each draw are used to run a new simulation, with all other model parameters as shown in the baseline specification.

Table 9 presents the results of the Monte Carlo simulation. The distribution of the macroeconomic effects of the proposal estimated by the Monte Carlo simulation are consistent with those in the baseline specification. Even at the 95th percentile, all macroeconomic variables decrease under the budget proposal and the budget proposal needs a social cost of carbon of $12 to enhance social efficiency. Taken together, the Monte Carlo simulation and the other sensitivity tests demonstrate that my baseline results are not purely products of my assumptions but would occur under a broad class of model specifications and elasticity values.
5 Conclusions

In this paper, I construct a computable general equilibrium model of the United States economy. My model includes endogenous resource supply, flexible substitution among consumer goods and production inputs, and externalities associated with energy use. I then use this model to examine proposed fossil fuel tax increases in President Obama’s 2014 budget proposal. This research has three main conclusions regarding the effects of the proposal and how energy taxes should be modeled.

First, descriptive analysis of the budget proposal’s provisions shows that the effects of the proposal on tax neutrality are mixed. Some provisions move the tax code towards neutrality, while others move it away, but the effects of most provisions are ambiguous.

Second, the budget proposal will reduce domestic fossil fuel production and will also reduce household welfare before carbon externalities are accounted for. The budget proposal discourages the investment in and the production of fossil fuels. The movement of economic activity out of fossil fuels worsens the allocation of consumption, labor, and capital across sectors of the economy and leads to lower productivity and household consumption. The social cost of carbon needs to be at least $14 per ton in order for reduced carbon emissions to make up for the social efficiency costs of the budget proposal.

Third, the innovations in my model significantly impact the estimates of the proposal’s effects. A partial equilibrium model could not analyze the efficiency costs of the proposal. Additionally, a general equilibrium model without flexible substitution would overstate the proposal’s reduction in carbon emissions or understate the efficiency loss from input substitution. Similarly, a model without externalities would underestimate the benefits of the proposal. Sensitivity tests further expose the limitations of the aforementioned approaches. These tests illustrate that both the inclusion of an energy resource and the general equilibrium effects of import substitution have important welfare impacts. By contrast, factors more accurately modeled by partial equilibrium models have little effect on welfare estimates. Therefore these results confirm the importance of considering general equilibrium effects, productive and consumptive efficiency, resource rents, and externalities.

References


Office of the Press Secretary (Mar. 2012). Remarks by the President on Oil and Gas Subsidies. URL: http://www.whitehouse.gov/the-press-office/2012/03/29/remarks-president-oil-and-gas-subsidies


A Model Data

A.1 Jorgenson (2007)

The data used in the regressions and simulations come from several sources. The first is a system of US national accounts covering the years 1960 to 2005 compiled by Jorgenson (2007). This data includes the quantity and price of output produced by all industries, the capital and labor purchased by each industry, the price of capital and labor purchased by each industry, and all intermediate inputs purchased by each industry from each industry. However, this data uses its own unique sector classification system that is roughly based on the Standard Industrial Classification (SIC). But the SIC has been superseded by the more modern North American Industrial Classification System (NAICS) and all other data sets use the NAICS format.

In order to convert Jorgenson (2007) to NAICS, I first convert the data to SIC. I then utilize the 1997 Economic Census’s Bridge between NAICS and SIC. The bridge gives the value of shipments and full-time equivalent employees in each SIC sector and how both are apportioned to the new NAICS sectors. The Jorgenson (2007) data on price, industry revenue, and input purchases are apportioned to NAICS sectors using the value of shipments in the bridge.

Input purchases by Jorgenson (2007) sectors are apportioned in three steps. First the SIC shipments in the bridge are aggregated to the level of the Jorgenson (2007) sectors:

\[ \text{Ship}^x_y = \sum_{z \in y} \text{Ship}^x_z \]  

(3)

where \( \text{Ship}^x_z \) are the value of shipments of SIC industry \( z \) apportioned to NAICS industry \( x \) and \( \text{Ship}^x_y \) are the value of shipments of Jorgenson (2007) industry \( y \) apportioned to NAICS industry \( x \). Note that each Jorgenson (2007) sector \( y \) contains many SIC sectors \( z \). Jorgenson (2007) sector 35 (government enterprises) has no corresponding SIC entry in the bridge but all other Jorgenson (2007) sectors directly correspond to particular SIC sectors. No SIC sector contains more than one Jorgenson (2007) sector. The next step gives the use of Jorgenson (2007) inputs by NAICS industries with the following formula:

\[ u^{\text{NAICS,JORG}}_{xjt} = \sum_{y \in \text{JORG}} \frac{\text{Ship}^x_y u^{\text{JORG,JORG}}_y}{\sum_{x \in \text{NAICS}} \text{Ship}^x_y} \]  

(4)

Here \( u^{\text{NAICS,JORG}}_{xjt} \) is the expenditure on Jorgenson (2007) input \( j \) by NAICS industry \( x \) at time \( t \), \( \text{Ship}^x_y \) are the value of shipments of Jorgenson (2007) industry \( y \) apportioned to NAICS sectors.
industry $x$, $u_{yjt}^{JORG,JORG}$ is the expenditure on Jorgenson (2007) input $j$ by Jorgenson (2007) industry $y$ at time $t$, and $JORG$ is the set of all sectors in Jorgenson (2007). Intuitively, Equation 4 says that the NAICS sector which is apportioned X percent of the value of shipments of a Jorgenson (2007) sector is also apportioned X percent of that sector’s Jorgenson (2007) input purchases.

However note that in Equation 4 the input $j$ is still a Jorgenson (2007) sector, not a NAICS sector: only the industry using the input was converted into the NAICS basis. In the second step, the inputs are converted into an NAICS basis as follows:

$$u_{xjt} = \sum_{j\in JORG} \frac{Ship_j^i u_{xjt}^{JORG,NAICS}}{\sum_{i\in NAICS} Ship_j^i}$$

where here $u_{xjt}$ is the expenditure on NAICS input $i$ by NAICS industry $x$ at time $t$. This fully converts Jorgenson (2007) input purchases of Jorgenson (2007) industries to NAICS input purchases by NAICS industries.

Next the revenue data in Jorgenson (2007) must be converted. The following equation is used to convert Jorgenson (2007) industry revenue to NAICS revenue:

$$u_{xt} = \sum_{j\in JORG} \frac{Ship_j^x u_{xt}^{JORG}}{\sum_{i\in NAICS} Ship_j^i}$$

where $u_{xt}$ is the revenue of NAICS industry $x$ at time $t$ and $u_{xt}^{JORG}$ is the revenue of Jorgenson (2007) industry $j$ at time $t$.

Finally, Jorgenson (2007) prices are converted to NAICS prices as follows:

$$p_{it} = \sum_{j\in SIC} \frac{u_{jt}^{SIC} Ship_j^i}{\sum_{i\in NAICS} Ship_j^i}$$

A.2 Other Data Sources

Additional data comes from the BEA Tables of the Use of Commodities by Industries from 1997-2010. This data set contains revenue for NAICS industries that is used for the years 2006 through 2010. In addition, this data set contains commodity demand data that is used for all years.

It is also worth noting exactly how variables such as “government investment” are defined as this variable draws from several different variables in this data set. Household consumption
expenditure data by industry are taken from “Personal consumption expenditures”. The private investment expenditures are equal to the sum of “Private fixed investment” and “Change in private inventories”. Exports are “Exports of goods and services”. Imports are “Imports of goods and services”. Government investment is the sum of “Federal Government defense: Gross investment”, “Nondefense: Gross investment”, “State and local government education: Gross investment”, and “State and local government gross investment, other”. Government consumption is equal to the sum of “Federal Government defense: Consumption expenditures”, “Nondefense: Consumption expenditures”, and “State and local government consumption expenditures, other”.

A third source of data is the BEA Gross Output Price Index from 1987-2010 which contains the price for each sector’s output. For most sectors, these prices can be used directly without adjustment. However, it is worth noting that my model’s sectors differ slightly from NAICS sectors. Sectors 211, 324, and 486 are not standalone sectors and are not contained in sectors 21, 31, and 48 as they normally are in the NAICS. The price of the sector (211, 324, or 486) commodity is removed from the price of commodity (21, 31, or 48) which no longer contains it as follows:

\[ p_{21t} = \frac{p_{21t}^{\text{OLD}} \cdot \text{Revenue}_{21t} - p_{211t} \cdot \text{Revenue}_{211t}}{\text{Revenue}_{21t} - \text{Revenue}_{211t}} \]  
\[ p_{31t} = \frac{p_{31t}^{\text{OLD}} \cdot \text{Revenue}_{31t} - p_{324t} \cdot \text{Revenue}_{324t}}{\text{Revenue}_{31t} - \text{Revenue}_{324t}} \]  
\[ p_{48t} = \frac{p_{48t}^{\text{OLD}} \cdot \text{Revenue}_{48t} - p_{486t} \cdot \text{Revenue}_{486t}}{\text{Revenue}_{48t} - \text{Revenue}_{486t}} \]  

where \( p_{kt}^{\text{OLD}} \) is the original price of commodity \( k \) at time \( t \) in the raw BEA data where \( k \in \{21, 31, 48\} \).

Note that Jorgenson (2007) also contains price data. The Jorgenson (2007) prices are used from 1960-1997. For years after 1997, the normalized BEA prices are used. This is done because the Jorgenson (2007) had to be converted from SIC and thus suffers from conversion error while the BEA data does not. This normalization is accomplished by setting prices in 1997 equal to the Jorgenson (2007) 1997 prices as follows:

\[ p_t = \begin{cases} 
 p^J_t & \text{if } t \leq 1997 \\
 \frac{p^J_{1997} \cdot p_{BEA}^{1997}}{p^J_{1997}} & \text{if } t > 1997 
\end{cases} \]
where \( p_{it} \) is the price of commodity \( i \) at time \( t \) used in the regression, \( p^I_{it} \) is the price from Jorgenson (2007) and \( p^{BEA}_{it} \) is the price from the BEA data set.

The final data source from the BEA is BEA Table: Full-Time Equivalent Employees by Industry for the years 1998-2010 which provides the full-time equivalent employees by industry.

Data for expenditures on energy resource acquisition come from two sources. The first is T-15. Oil and Natural Gas Exploration and Development Expenditures from 1977 to 2009 provides the expenditures by financial reporting system (FRS) companies on the acquisition of land containing oil and gas resources. However, T-15 only includes FRS firms. In order to find the expenditures of all firms, reserve additions from these and non-FRS companies are taken from T-19. Oil and Natural Gas Reserves: FRS and Industry, 2008 to 1977.

B Model Equations

B.1 Variable Definitions

Tables 10 and 11 define the variables used in the model, excluding the elasticity parameters of Table 2. Table 10 lists the variables that refer to the price, quantity, or expenditure on various commodities. If a variable is missing a sector \( x \) subscript, then it is a vector of the prices for all sectors. The variable with a time \( t \) subscript are only used in the regression: in the simulation, the model is solved for a steady-state equilibrium in the year 2005.

Table 11 defines the parameters used in the constant elasticity of substitution (CES) cost functions that give the price of domestic output and composite output. These parameters are determined by calibration in order to give the observed cost shares spent on imported versus domestic products for all sectors or on energy resources versus capital, labor, energy, and materials for oil and gas extraction.

B.2 Regression

B.2.1 Regression Equations

The regression which parametrizes the translog cost function in Equation 1 deals not only with that equation but an entire system of equations. The additional equations are the input

\[50\text{Available online at http://www.eia.gov/cfapps/frs/frstables.cfm?tableNumber=15&startYear=1977&endYear=2009&loadAction=Apply+Changes}\]

\[51\text{Available online at http://www.eia.gov/cfapps/frs/frstables.cfm?tableNumber=19&startYear=2003&endYear=2009}\]
Table 10: Commodity Variable Notation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{x_it}$</td>
<td>Price of input $i$ to industry $x$ at time $t$</td>
</tr>
<tr>
<td>$p_{x_kt}$</td>
<td>Price of capital to industry $x$ at time $t$</td>
</tr>
<tr>
<td>$p_{x_lt}$</td>
<td>Price of labor to industry $x$ at time $t$</td>
</tr>
<tr>
<td>$p_{x_rt}$</td>
<td>Price of resource to industry $x$ at time $t$</td>
</tr>
<tr>
<td>$p_{xi}$</td>
<td>Price of input $i$ to industry $x$</td>
</tr>
<tr>
<td>$p_k$</td>
<td>Vector of prices of capital</td>
</tr>
<tr>
<td>$p_l$</td>
<td>Vector of prices of labor</td>
</tr>
<tr>
<td>$p_r$</td>
<td>Vector of prices of resource</td>
</tr>
<tr>
<td>$p_{dom}$</td>
<td>Vector of prices of domestic output</td>
</tr>
<tr>
<td>$p_{imp}$</td>
<td>Vector of prices of imported output</td>
</tr>
<tr>
<td>$p_{com}$</td>
<td>Vector of prices of composite import/domestic commodity</td>
</tr>
<tr>
<td>$p_c$</td>
<td>Prices of the household composite consumption good</td>
</tr>
</tbody>
</table>

Notes: Only the price variables are given in the table given a price variable $p_z$, the associated quantity is $q_z$ and the associated expenditure is $p_z q_z \equiv u_z$.

Table 11: CES Parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_r$</td>
<td>Parameter for Equation 32: Domestic output cost function</td>
</tr>
<tr>
<td>$\alpha_{KLEM}$</td>
<td>Parameter for Equation 32: Domestic output cost function</td>
</tr>
<tr>
<td>$\alpha_{import}$</td>
<td>Parameter for Equation 38: Composite output cost function</td>
</tr>
<tr>
<td>$\alpha_{domestic}$</td>
<td>Parameter for Equation 38: Composite output cost function</td>
</tr>
</tbody>
</table>

cost shares, one for each input, given by

$$share_{xoit} = \sum_{j=1}^{N} \beta_{xij}^{\text{substitution}} \ln(p_{x_it}) + \beta_{x_i}^{\text{share trend}} t + \beta_{x_i}^{\text{share constant}}$$  \hspace{0.5cm} (12)

where $share_{xoit}$ is the share of the total cost of output $o$ for industry $x$ at time $t$ that is spent on input $i$.

However, these equations are parametrized indirectly. Because the translog cost function is not guaranteed to be concave, a Cholesky decomposition was used to ensure the concavity. The parameters of the Cholesky decomposition are those actually estimated by the regression. In addition, the requirements of homogeneity, product exhaustion, and symmetry impose further constraints on the parameters. Taking into account all these restrictions, the actual regression is performed on the following system of 3 equations (labeled Equations 13, 14, and 15) when
N=4 and inputs $i = \{1, 2, 3, 4\}$. For brevity $\beta_{xi}^{\text{share constant}} \equiv \beta_{xi}^{sc}$.

\[
\begin{align*}
\text{share}_{x0t} &= \\
&\beta_{x1}^{sc} - (\beta_{x1}^{sc} + \beta_{x1}^{sc2} + e^{2d_{x11}}) \ln(p_{x1t}) - (\beta_{x2}^{sc} + \beta_{x2}^{sc2} + e^{2d_{x12}}) \ln(p_{x2t}) \\
&\quad - (\beta_{x3}^{sc} + \beta_{x3}^{sc2} + e^{d_{x11} + d_{x12}}) \ln(p_{x3t}) + (0 + (\beta_{x1}^{sc} + \beta_{x1}^{sc2} + e^{2d_{x11}}) \\
&\quad + (\beta_{x1}^{sc} + \beta_{x1}^{sc2} + e^{d_{x11} + d_{x12}}) + (\beta_{x2}^{sc} + \beta_{x2}^{sc2} + e^{d_{x11} + d_{x13}}))) \ln(p_{x4t}) + \beta_{x1}^{\text{share trend year}} + \varepsilon_{x0t} 
\end{align*}
\]

\[
\begin{align*}
\text{share}_{x02t} &= \\
&\beta_{x2}^{sc} - (\beta_{x1}^{sc} + \beta_{x2}^{sc2} + e^{d_{x11} + d_{x12}}) \ln(p_{x1t}) - (\beta_{x2}^{sc} + \beta_{x2}^{sc2} + e^{2d_{x12}}) \ln(p_{x2t}) \\
&\quad - (\beta_{x3}^{sc} + \beta_{x3}^{sc2} + e^{d_{x11} + d_{x12}} + e^{d_{x22} + d_{x23}}) \ln(p_{x3t}) + (0 + (\beta_{x1}^{sc} + \beta_{x1}^{sc2} + e^{d_{x11} + d_{x12}}) \\
&\quad + (\beta_{x1}^{sc} + \beta_{x1}^{sc2} + e^{2d_{x12}}) + (\beta_{x2}^{sc} + \beta_{x2}^{sc2} + e^{d_{x12} + d_{x13}} + \\
&\quad + e^{d_{x22} + d_{x23}})) \ln(p_{x4t}) + \beta_{x2}^{\text{share trend year}} + \varepsilon_{x02t} 
\end{align*}
\]

\[
\begin{align*}
\text{share}_{x03t} &= \\
&\beta_{x3}^{sc} - (\beta_{x1}^{sc} + \beta_{x2}^{sc} + e^{d_{x11} + d_{x12}}) \ln(p_{x1t}) - (\beta_{x2}^{sc} + \beta_{x3}^{sc} + e^{d_{x11} + d_{x12}} + e^{d_{x22} + d_{x23}}) \ln(p_{x2t}) \\
&\quad - (\beta_{x3}^{sc} + \beta_{x3}^{sc2} + e^{d_{x11} + d_{x12}} + e^{2d_{x23}}) \ln(p_{x3t}) + (0 + (\beta_{x1}^{sc} + \beta_{x1}^{sc2} + e^{d_{x11} + d_{x12}}) \\
&\quad + (\beta_{x2}^{sc} + \beta_{x2}^{sc2} + e^{d_{x12} + d_{x13}} + e^{d_{x22} + d_{x23}}) + (\beta_{x3}^{sc} + \beta_{x3}^{sc2} + e^{2d_{x12}} + \\
&\quad + e^{2d_{x23}} + e^{d_{x11}})) \ln(p_{x4t}) + \beta_{x3}^{\text{share trend year}} + \varepsilon_{x03t} 
\end{align*}
\]

where $\varepsilon_{x0jt}$ is the error term. However, not all cost function (Equation 1) terms are present in Equations 13, 14 and 15. And note that the $d_{xij}$ terms do not appear in the cost function at all. The remaining terms for the cost function are derived from the terms in Equations 13, 14 and 15 as follows in Equations 16 through 27.

\[
\begin{align*}
\beta_{x11}^{\text{substitution}} &= -(\beta_{x1}^{sc2} + e^{2d_{x11}}) + \beta_{x1}^{sc} \\
\beta_{x12}^{\text{substitution}} &= -(\beta_{x1}^{sc} + \beta_{x1}^{sc2} + e^{d_{x11} + d_{x12}}) \\
\beta_{x13}^{\text{substitution}} &= -(\beta_{x1}^{sc} + \beta_{x1}^{sc2} + e^{d_{x11} + d_{x13}}) \\
\beta_{x14}^{\text{substitution}} &= 0 - \beta_{x11}^{\text{substitution}} - \beta_{x12}^{\text{substitution}} - \beta_{x13}^{\text{substitution}}
\end{align*}
\]
\[
\beta_{x22}^{\text{substitution}} = -(\beta_{x2}^{sc} + \epsilon^2 d_{x12} + \epsilon^2 d_{x22}) + \beta_{x2}^{sc} \\
\beta_{x23}^{\text{substitution}} = -(\beta_{x2}^{sc} \beta_{x3}^{sc} + \epsilon^2 d_{x12} + \epsilon^2 d_{x22} + \epsilon^2 d_{x23}) \\
\beta_{x24}^{\text{substitution}} = 0 - \beta_{x12}^{\text{substitution}} - \beta_{x22}^{\text{substitution}} - \beta_{x23}^{\text{substitution}} \\
\beta_{x33}^{\text{substitution}} = -(\beta_{x3}^{sc} + \epsilon^2 d_{x13} + \epsilon^2 d_{x23} + \epsilon^2 d_{x33}) + \beta_{x3}^{sc} \\
\beta_{x34}^{\text{substitution}} = 0 - \beta_{x23}^{\text{substitution}} - \beta_{x33}^{\text{substitution}} - \beta_{x13}^{\text{substitution}} \\
\beta_{x44}^{\text{substitution}} = 0 - \beta_{x14}^{\text{substitution}} - \beta_{x24}^{\text{substitution}} - \beta_{x34}^{\text{substitution}} \\
\beta_{x44}^{\text{share trend}} = 0 - \beta_{x1}^{\text{share trend}} - \beta_{x2}^{\text{share trend}} - \beta_{x3}^{\text{share trend}}.
\]

Additionally, since prices are directly observed, not costs, I assume that the domestic price of output is equal to the cost of producing that industry’s KLEM output

\[
c_{x,KLEM,t} = p_{x,dom,t}.
\]

**B.2.2 Regularity Conditions**

Not all functions are cost functions. In order for a function to be a cost function, it must be the dual representation of a well-behaved production function. This imposes the following requirements on the cost function (McFadden, 1978):

1. Positivity. The cost function is positive for positive input prices.
2. Homogeneity. The cost function is homogeneous of degree one in the input prices.
3. Monotonicity. The price function is increasing in the input prices.
4. Concavity. The price function is concave in the input prices.

Many functional forms for cost functions satisfy these 4 requirements for all parameter values. However, the translog cost function does not. For a translog cost function to satisfy the above 4 requirements, it must satisfy the following 5 conditions (Jorgenson, 1986):

1. Positivity. The cost function is positive for positive input prices.
2. Homogeneity. The cost function is homogeneous of degree one in the input prices.
3. Monotonicity. The price function is increasing in the input prices.
4. Concavity. The price function is concave in the input prices.
5. Symmetry. The cost function is symmetric in the input prices.
1. Homogeneity. The value shares and the rate of technical change are homogeneous of degree zero in the input prices.

2. Product Exhaustion. The sum of the value shares is equal to unity.

3. Symmetry. The matrix of share elasticities is symmetric.

4. Nonnegativity. The value shares must be nonnegative.

5. Monotonicity. The matrix of share elasticities must be nonpositive definite.

The regression to parametrize the translog cost function must be implemented with these requirements in mind in order to avoid parameter values that violate them and thus lead to the use of a function which is not a cost function. The following cross equation restrictions on parameter values:

\[ \sum_{i} \beta_{x_i}^{\text{shareconstant}} = 1 \quad \forall x \]  
\[ \sum_{i} \beta_{x_i}^{\text{sharetrend}} = 0 \quad \forall x \]  
\[ \beta_{xij}^{\text{substitution}} = \beta_{xji}^{\text{substitution}} \quad \forall x, i, j \]  

\[ \text{(29)} \]  
\[ \text{(30)} \]  
\[ \text{(31)} \]

guarantee that the cost function satisfies the homogeneity (Equation 29), product exhaustion (Equation 30), and symmetry (Equation 31) conditions. Nonnegativity and monotonicity cannot be guaranteed but must be checked for using the regression’s estimated parameter values. This is accomplished by taking the estimated parameter values and the full data set of input prices used to estimate them and determining for what percent of these input prices the resultant cost functions are nonnegative and monotonic.

Table 12 presents results of this calculation. Almost all cost shares are positive for all input prices. The very few exceptions typically occur for industries that use little to none of a particular commodity. This would allow difference in scale between that commodity’s cost share and the cost shares of the other commodities to cause negative cost shares for the less used commodity through rounding errors.

The concavity of the cost function in input prices is equivalent to the monotonicity requirement. This is determined by calculating the cost function’s Hessian and determining whether

\[ \text{These are the mean values of the summary statistics averaged over all industries. See Appendix E for full results.} \]
Table 12: Regression Statistics: Nonnegativity and Monotonicity

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Nonnegative (%)</th>
<th>Monotonic (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>100</td>
<td>na</td>
</tr>
<tr>
<td>21</td>
<td>100</td>
<td>na</td>
</tr>
<tr>
<td>211</td>
<td>99</td>
<td>na</td>
</tr>
<tr>
<td>22</td>
<td>100</td>
<td>na</td>
</tr>
<tr>
<td>23</td>
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<td>na</td>
</tr>
<tr>
<td>31</td>
<td>100</td>
<td>na</td>
</tr>
<tr>
<td>324</td>
<td>99.9</td>
<td>na</td>
</tr>
<tr>
<td>42</td>
<td>100</td>
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<td>44</td>
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<td>na</td>
</tr>
<tr>
<td>48</td>
<td>100</td>
<td>na</td>
</tr>
<tr>
<td>486</td>
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</tr>
<tr>
<td>51</td>
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</tr>
<tr>
<td>52</td>
<td>100</td>
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<td>55</td>
<td>100</td>
<td>na</td>
</tr>
<tr>
<td>56</td>
<td>100</td>
<td>na</td>
</tr>
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<td>61</td>
<td>100</td>
<td>na</td>
</tr>
<tr>
<td>62</td>
<td>100</td>
<td>na</td>
</tr>
<tr>
<td>71</td>
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<td>81</td>
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<td>82.6</td>
</tr>
<tr>
<td>N</td>
<td>100</td>
<td>na</td>
</tr>
<tr>
<td>KLEM</td>
<td>na</td>
<td>68.2</td>
</tr>
</tbody>
</table>

Notes: There are different numbers of entries in each column because every commodity which is an input has a cost share, which defines nonnegativity. However, only composite commodities have cost functions, which defines monotonicity.
the Hessian is negative semidefinite or not. However, this procedure involves calculating the Hessian’s eigenvalues using both multiplication and addition. Because of this, even small rounding errors can significantly change the outcome. Therefore, I define a cost function as concave if given any eigenvalue $\lambda$ of its Hessian, $\lambda \leq 10^{-16}$. $10^{-16}$ was chosen because the computer program used to calculate the Hessian has 16 digits of precision.

Table[12] indicates that for the majority of input prices, the cost functions are concave. Most importantly, the top level output KLEM is concave for 68.2 percent of input prices. However, at the lower level commodities are not always concave in input prices. Concavity is a significant problem for commodities E and M. I attempt to mitigate the concavity problem through the use of a Cholesky decomposition as detailed in Appendix[B.2.1] But Table[12]'s results are what is obtained after all efforts to improve the function’s concavity have been implemented.

B.3 Other Cost Functions

The translog cost function describes how the various KLEM goods, the domestic outputs of each industry, are produced. However, the KLEM good cannot be directly used to satisfy demand for a commodity. In order to create composite output that can satisfy demand, KLEM must be combined with the energy resource to create domestic output and then domestic output must be combined with imports to produce composite output. This process is diagrammed in Figure[3]

![Figure 3: Tiers and Cost Functions to Create Composite Output](image)

Notes: See section[3.2.3.1] for the tier structure of producing KLEM.

However, the step of combining KLEM and the energy resource only applies to the industry of oil and gas extraction. For all other industries, the energy resource is not used: $q_{x,\text{resource}} = 0$ and $p_{x,\text{dom}} = p_{x,\text{KLEM}}$ if $x \neq$ oil and gas extraction.
B.3.1 Domestic Output

Domestic output is created using a constant elasticity of substitution cost function with two inputs, KLEM, the output of the translog cost function, and the energy resource. The cost function for domestic output is

\[ c_{\text{dom}}(p_{\text{KLEM}}, p_r) = \frac{1}{\phi_{\text{dom}}} \left( \alpha_r p_r^{1-\theta_r} + \alpha_{\text{KLEM}} p_{\text{KLEM}}^{1-\theta_{\text{KLEM}}} \right)^{1/\theta_r} \]  

(32)

with

\[ \alpha_{\text{KLEM}} = 1 - \alpha_r \]  

(33)

and

\[ \phi_{\text{dom}} = \left( \alpha_r p_r^{1-\theta_r} + \alpha_{\text{KLEM}} p_{\text{KLEM}}^{1-\theta_{\text{KLEM}}} \right)^{1/\theta_r} / p_{\text{dom},2005}. \]  

(34)

The cost share of the resource is

\[ \frac{u_r}{u_r + u_{\text{KLEM}}} = \frac{\alpha_r p_r^{1-\theta_r}}{\alpha_r p_r^{1-\theta_r} + \alpha_{\text{KLEM}} p_{\text{KLEM}}^{1-\theta_{\text{KLEM}}}} \]  

(35)

and the value of \( \alpha_{\text{KLEM}} \) is calibrated for the year 2005 by solving for the \( \alpha_{\text{KLEM}} \) that gives the 2005 cost share of the resource is

\[ \frac{u_{r,2005}}{u_{r,2005} + u_{\text{KLEM},2005}} = \frac{\alpha_r p_{r,2005}^{1-\theta_r}}{\alpha_r p_{r,2005}^{1-\theta_r} + \alpha_{\text{KLEM}} p_{\text{KLEM},2005}^{1-\theta_{\text{KLEM},2005}}}. \]  

(36)

The assumption of perfectly competitive markets means that \( p_{\text{KLEM}} \) is equal to the cost times one plus the production tax rate

\[ p_{\text{dom}} = c_{\text{dom}}(1 + \tau_{\text{production}}). \]  

(37)

B.3.2 Imports and Composite Output

Like domestic output, composite output is created using a constant elasticity of substitution cost function in two variables: the price of domestic output \( p_{\text{dom}} \) and imports \( p_{\text{import}} \).

\[ p_{\text{com}} = c_{\text{com}}(p_{\text{dom}}, p_{\text{import}}) = \frac{1}{\phi_{\text{com}}} \left( \alpha_{\text{dom}} p_{\text{dom}}^{1-\theta_{\text{dom}}} + \alpha_{\text{import}} p_{\text{import}}^{1-\theta_{\text{import}}} \right)^{1/(1-\theta_{\text{import}})} \]  

(38)
where
\[
\phi_{com} = (\alpha_{dom}^{\theta_{Arm}} + \alpha_{import}^{\theta_{Arm}})^{1/(1-\theta_{Arm})}.
\]
(39)

This value of \( \phi \) was chosen so that if input prices are equal, they equal composite price
\[
c_{com}(x,x) = x.
\]
(40)

Solving for \( \alpha_{import} \) in terms of the other variables gives
\[
\alpha_{import} = \left( \frac{u_{import}}{u_{domestic} + u_{import}} \left( \frac{p_{dom}}{p_{import}} \right)^{1-\theta_{Arm}} \right) \frac{1}{\theta_{Arm}}
\]
(41)

and
\[
\alpha_{import} = 1 - \alpha_{dom}.
\]
(42)

\( p_{import} \) is assumed to be exogenous to the model. For convenience, I assume \( p_{import} = p_{dom,2005} \) but any value of \( p_{import} \) can be used without affecting results due to the way the other parameters are defined.

In order to parametrize \( \alpha_{import} \), it is partially calibrated as
\[
\alpha_{import} = \left( \frac{u_{import,2005}}{u_{dom,2005} + u_{import,2005}} \left( \frac{p_{dom}^*}{p_{import}} \right)^{1-\theta_{Arm}} \right) \frac{1}{\theta_{Arm}}
\]
(43)

where \( p_{dom}^* \) is the value of \( p_{dom} \) for a simulation using the model baseline specification’s elasticity parameter values under current law. \( p_{dom}^* \) is used instead of \( p_{dom,2005} \) which would calibrate \( \alpha_{import} \) for 2005 data.

Although \( p_{dom,2005} \) could be used, that would be a mistake. Because portions of the model such the translog firm cost and consumer expenditure functions are not calibrated, 2005 prices are not equilibrium prices for the model, but differ slightly. This is important for import substitution because of the extremely high Armington elasticities involved, especially for the critically important fossil fuel production sectors. These large elasticities mean that the non-equilibrium prices of \( p_{dom,2005} \) would cause imports to be very different under the model’s current law equilibrium than the empirical values in the data. Calibrating \( \alpha_{import} \) off of an equilibrium price such as \( p_{dom}^* \) ensures that the model’s equilibrium import levels are closer to the empirical values than would be achieved with calibration to 2005 prices.
B.4 Removing the Energy Resource from the Capital Stock

Since the “other” data include energy resource acquisition expenditures as part of capital expenditures, these expenditures are subtracted as follows:

\[ q_{jk,t,BASELINE} = q_{jk,2005} - \frac{u_{r,2005}}{P_{jk,2005}}. \] (44)

Some translog equation parameters are similarly adjusted to give the proper cost shares of each input. For any \( i \in \{k,l,e,m\} \), if \( x = \) oil and gas extraction

\[ \beta_{xi}^{\text{shareconstant}} = \beta_{xi}^{\text{shareconstant,OLD}} + \frac{u_{x,i,BASELINE}}{u_{x,o,BASELINE}} - \frac{u_{x,i,2005}}{u_{x,o,2005}}. \] (45)

For the same reason, the prices observed in the data set are \( p_{dom} \), not \( p_{KLEM} \). For most industries, the two are identical. But for oil and gas extraction where \( p_{dom} \neq p_{KLEM} \), \( p_{KLEM} \) is imputed from \( p_{dom} \) as follows:

\[ p_{KLEM} = p_{dom} \prod_{i \in \{k,l,e,m\}} \left( p_{xi,2005} \right)^{\frac{u_{x,i,BASELINE}}{u_{x,o,BASELINE}}} - \frac{u_{x,i,2005}}{u_{x,o,2005}}. \] (46)

Note however that since \( AQC \) (defined in Appendix B.5.3) can only be calculated for a single year and not the entire data set, the regression to parametrize the translog cost function of oil and gas extraction includes resource acquisition expenditures as part of capital. This implicitly assumes that in the data, resource acquisition costs are a constant fraction of capital expenditures, either because \( \frac{p_k}{p_r} \) is constant or \( \theta_r = 0 \).

B.5 Supply Functions

B.5.1 Capital

Total capital supply in the model is determined by the actual total capital supply in 2005 (net of resource subtraction, see Appendix B.4), the post-tax capital rental rate, and the price elasticity of capital supply as follows:

\[ \sum_x q_{zk} = \sum_x q_{z,k,BASELINE} \left( \frac{(1 - \tau_k)p_k/p_c}{(1 - \tau_{k,2005})p_{k,2005}/p_{c,2005}} \right)^{\theta_{\text{capital}}}. \] (47)
Capital is assumed to be perfectly mobile across industries such that for any two industries $x$ and $y$:

$$(1 - \tau_{xk})p_{zk} = (1 - \tau_{yk})p_{yk}. \quad (48)$$

### B.5.2 Labor

Total labor supply in the model is determined by the actual total labor supply in 2005, the post-tax wage rate, and the substitution elasticity of labor supply as follows:

$$\sum_x q_{xl} = \sum_x q_{xl,2005} \left( (1 - \tau_l)p_l / p_c (1 - \tau_{l,2005})p_{l,2005} / p_{c,2005} \right)^{\theta_{labor}}. \quad (49)$$

Labor is mobile across sectors but differential wage rates across sectors are assumed to be exogenously determined such that the relative wage rate across sectors stays fixed:

$$(1 - \tau_l)p_l = \alpha (1 - \tau_{l,2005})p_{l,2005} \quad (50)$$

for some $\alpha \in \mathbb{R}$.

### B.5.3 Energy Resource

The total expenditures on the energy resource in 2005 is derived from the raw data as

$$u_{r,2005} = \sum_{t=2003}^{2005} AQC_t^{FRS} \sum_{t=2003}^{2005} R_t^{All} / 3 \sum_{t=2003}^{2005} R_t^{FRS}. \quad (51)$$

where $AQC_t^j$ is the expenditure by companies of type $j$ on proved and unproved acreage in the US in year $t$ in millions of 2009 dollars. $R_t^{All}$ is total reserve additions of oil and gas in the US in millions of barrels of oil equivalents. $R_t^{FRS}$ is total reserve additions by Financial Reporting System (FRS) firms of oil and gas in the US in millions of barrels of oil equivalents. This method implicitly assumes FRS and non-FRS firms are have the same cost of reserve additions. As suggested in U.S. Energy Information Administration (2011), three-year averages of the variables are used. $AQC_{Baseline}$ is then deflated from 2009 to 2005 dollars using the Urban

---

531 billion cubic feet of natural gas equals 0.178 million barrels of oil equivalents (U.S. Energy Information Administration, 2011).
Consumer Price Index. From this, total resource supply in the model is equal to

\[ q_r = q_{r, 2005} \left( \frac{(1 - \tau_r) p_r / p_c}{(1 - \tau_{r, 2005}) p_{r, 2005} / p_{c, 2005}} \right)^{\theta_{resource}}. \] (52)

**B.6 Demand Functions**

Demand for the composite commodities comes from 5 sources: exports, government demand, household consumption demand, and household investment demand or

\[ q_{\text{final}} = q_{\text{export}} + q_{\text{government}} + q_{\text{consumption}} + q_{\text{investment}}. \] (53)

The market clearing condition of the equilibrium requires demand to equal supply:

\[ q_{\text{final}} = q_{\text{com}}. \] (54)

This section describes the various sources of final demand for the composite good in more detail.

**B.6.1 Household Consumption Demand**

There is no explicit functional form for the consumer demand function: it is implicitly defined by the series of nested translog expenditure functions. The price of household consumption resulting from the translog expenditure functions is \( p_c \) and the quantity of consumption is \( q_c \).

**B.6.2 Firm Intermediate Good Demand**

There is no explicit functional form for the firm intermediate good demand function: it is implicitly defined by the series of nested translog cost functions.

**B.6.3 Government Demand**

Government demand is equal to government consumption and investment spending and equal in nominal value to its 2005 spending:

\[ q_{\text{government}} = q_{\text{government}, 2005} \frac{p_{\text{com}}}{p_{\text{com, 2005}}}. \] (55)
B.6.4 Household Investment Demand

Household investment demand of composite commodity is equal to:

\[ q_{investment} = \sum_x q_{x,k,2005} \frac{p_{com}}{p_{com,2005}} S_{inv,2005} \]  \hspace{1cm} (56)

where \( q_{investment} \) is vector of investment demand for the composite commodity and \( S_{inv,2005} \) is equal to a vector of spending for private investment in 2005 for each industry.

B.6.5 Export Demand

Export demand is isoelastic in the price of the composite commodity:

\[ q_{export} = q_{export,2005} \left( \frac{p_{com}}{p_{com,2005}} \right)^{\theta_{export}}. \]  \hspace{1cm} (57)

B.6.6 Household Income and Spending

Households own all factors of production and receive income from their use. Post-tax income is calculated from the supply of capital, labor, and energy resources:

\[ I_j = \sum_x q_{x,k} p_{x,k} (1 - \tau_{x,k}) + q_{x,l} p_{x,l} (1 - \tau_{x,l}) + q_{x,r} p_{x,r} (1 - \tau_{x,r}) \]  \hspace{1cm} (58)

where \( x \) indexes industry.

Household spending is given by:

\[ S = \sum_x p_{com,x} (q_{consumption,x} + q_{investment,x}) \]  \hspace{1cm} (59)

and the budget condition requires spending to equal income:

\[ S = I. \]  \hspace{1cm} (60)

B.7 Household Utility

A representative household maximizes utility by allocating income between consumption and leisure. This occurs in a two step process detailed in Figure 4. The household first allocates income between leisure and composite consumption. Then the household allocates consumption spending among different consumption goods through the translog expenditure function.
Figure 4: Household Utility

Utility

\[ \begin{align*}
\text{Consumption} & \quad \text{Leisure} \\
E & \quad M \quad \text{Translog}
\end{align*} \]

Notes: See section 3.2.3.1 for the tier structure of producing KLEM. Consumers do not use capital, labor, or noncompeting imports but otherwise use the same structure as producers.

Expressed in terms of of the composite consumption good \( c \), labor supply \( l \), household utility is

\[ U(q_c, q_l, b) = q_c - L_0 q_l^{1+1/\theta_{labor}} \]  \hspace{1cm} (61)

where

\[ L_0 = q_l^{-1/\theta_{labor}} \frac{\theta_{labor}}{\theta_{labor} + 1} \frac{(1 - \tau_{l,2005})p_{l,2005}}{p_{c,2005}}. \]  \hspace{1cm} (62)

The utility function is linear in consumption and the form of the labor term is chosen in order to generate the isoelastic labor supply of Equation 49.

B.7.1 Externalities

The change in carbon emissions from the budget proposal is equal to

\[ \Delta C = \Delta q_{min} C \]  \hspace{1cm} (63)

where \( \Delta q_{min} \) is equal to the smallest percent decrease in output by a fossil fuel producing sector and \( C \) is the total US 2011 greenhouse gas emissions in metric tons of carbon dioxide equivalents from Table ES-2 in http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2011.pdf.

Greenhouse gas emissions are not the only externalities from the production or use of fossil fuels. Other sources of externalities include water use, air and water pollution, and energy security. These other externalities are not explicitly included in the model.
B.8 Government Revenue

Total government tax revenue $T_{total}$ is equal to the sum of the revenue from all sources: capital, labor, energy resources, and production as given by the following equations:

$$T_{capital} = \sum_x q_x p_{xk} \tau_{capital,x}$$  

(64)

$$T_{labor} = \sum_x q_x p_{xl} \tau_{labor,x}$$

(65)

$$T_{resource} = q_r p_r \tau_{resources}$$

(66)

$$T_{production} = \sum_x q_{dom,x} p_{dom,x} \frac{\tau_{production,x}}{1 + \tau_{production,x}}$$

(67)

$$T_{total} = T_{capital} + T_{labor} + T_{resource} + T_{production}.$$  

(68)

C Current Law Tax Rates

The provisions and their neutrality are only truly relevant through their effect on the entire tax system. Therefore, the individual tax changes proposed by President Obama need to be considered in the context of the existing taxes and subsidies faced by fossil fuel producers. Treasury (2013) has stated that tax preferences encourage more investment in fossil fuel production than would occur under a neutral tax system. Nonetheless, research in recent years on the tax rates faced by the energy sector have displayed mixed results.

However, both previous research and the president’s budget have focused on firm level capital taxes. Yet in addition to these capital taxes, production taxes (e.g. severance, excise, and property taxes) are also imposed on the extraction and refining of fossil fuels. These production taxes on fossil fuels are a larger source of revenue than corporate income taxes, but have received comparatively little attention.

In this section, I review the taxes and tax rates facing consumers, producers, capital, and labor involved with fossil fuels and compare them to those faced by the economy as a whole. I examine the issues raised by the Obama administration regarding firm capital taxes, but I also include other agents (e.g. labor and consumers) and other taxes (e.g. severance, excise, and property). I review previous work on estimating the effective rate imposed by these taxes on fossil fuel producing sectors and how their rates compare to those of the rest of the economy. I then calculate additional effective tax rates of my own that include both firm production and
capital taxes.

However, there are multiple methods to measure effective tax rates. Upon reviewing the effective tax rate measures that have been used by the literature, I find that although the marginal effective tax rate (METR) measure is the gold standard, the less used average effective tax rate (AETR) method is more appropriate in this circumstance.\(^{54}\) I then calculate effective tax rates for the sector using the AETR methodology.

C.1 Background

The main taxes imposed on capital income are state and federal corporate income taxes and personal income taxes on capital gains and dividends. The effect of these taxes on the pre-tax and post-tax rates of return can be summarized through the marginal effective tax rate (METR) on investment. The marginal effective tax rate on investment is the rate by which capital taxes reduce the pre-tax rate of return on investment. For example, if the marginal investment in a new oil well earned a pre-tax 12 percent return but taxes reduce that return to 9 percent, the marginal effective tax rate would be \((12-9)/12 = 25\) percent. An effective tax rate differs from the statutory tax rate in that it applies to the income earned over the lifetime of an investment and is able to account for the effects of inflation, the difference between tax and economic depreciation, and the difference in the taxation of returns to debt and equity.

The marginal investment is the investment that earns a rate of return exactly equal to the cost of capital. The marginal investment is the critical one for determining the aggregate level of investment because a firm will invest in all investments opportunities with higher post-tax rates of return than the breakeven rate and not invest in any with lower. Reducing the rate of return of an investment that is currently at the breakeven rate would cause the firm to no longer undertake the project and thus reduce aggregate investment.

The literature has produced many estimates of the marginal tax rate for different types of capital assets in CBO (2005), Mackie (2002), Ernst & Young (2007), and Metcalf (2009). However, there is large variation between estimated rates and no consensus on whether fossil fuel production is more or less taxed than other sectors.

CBO (2005) calculates the METR from federal taxes for a wide variety of very broad asset categories.\(^{55}\) They find the overall METR on capital assets from all businesses is 24.2 percent.\(^{54}\) The average effective tax rate is also known simply as the average tax rate.

\(^{55}\) The taxes included in the CBO analysis are federal taxes on corporate profits, dividends, long-term capital gains, short-term capital gains, interest income, mortgage interest deductions, unincorporated business income,
and the METR on corporations is 26.3 percent. But the METRs for C corporation assets in
the fossil fuel industry vary from 9.2 to 24.9 percent.\footnote{56} However, note that these results are for
particular assets used only by energy industries, not the industry as a whole.

Mackie (2002) also calculates METRs for assets but then aggregates them over industries
as well. He finds a high METR on energy assets such as mining and oil field machinery (33.5
percent) and a lower METR on mining, shafts, and wells (16.9 percent). When aggregated
at the industry level, crude petroleum and gas has an METR of 24.6 percent while petroleum
refining’s METR is 35.6. By comparison, the METR for the corporate sector is on average 32.2
and the METR for the entire economy is 19.8 percent.

Other papers have calculated the METR for the energy sector but did not include estimates
for other sectors. Ernst & Young (2007) looks at the energy sector specifically but only includes
the federal corporate income tax in their calculation. They find a 21.6 percent METR for
petroleum refining, which is much lower than that of Mackie (2002). Metcalf (2009) provides
another calculation of the METR of assets used in fossil fuel production. Metcalf’s calculation
includes some tax credits, but the only taxes included are the federal corporate income tax and
the average state corporate income tax. His results show significant variation in the METR
faced by different capital assets in the energy sector, with METRs ranging from a high of 27.0
percent for other natural gas pipelines to a low of -13.5 percent for oil drilling by non-integrated
firms. However, his METRs for oil drilling by integrated firms, petroleum refining, and natural
gas gathering pipelines are all in the range of 15.2 to 19.1 percent. These papers provide some
perspective but are less helpful in determining the relative tax burdens of fossil fuel production
and other sectors since they do not present comparable economy-wide average METRs using
the same methodology.

However, capital taxes are not the only taxes that apply to producers of fossil fuels. Fossil
fuel production also faces a large number of other taxes such as sales, property, severance, and
excise taxes. As seen in Table \ref{tab:taxes}, total payments for these taxes, less subsidies, by fossil fuel
producing sectors exceed payments for corporate income taxes.\footnote{57} However, to the best of my
knowledge, these taxes have not been combined and summarized, either with each other or with
capital taxes, the way the METR literature has done for taxes on capital investment.

\footnote{56}C corporations are corporations that are taxed separately from their owners. The corporate income tax
applies solely to C corporations.

\footnote{57}Both corporate income tax statistics and the other production tax statistics include all such taxes at the
federal, state, and local levels.
I utilize average effective tax rates (AETRs), as opposed to marginal effective tax rates (METRs), in order to aggregate the effects of these taxes. Collins and Shackelford (1995) and Fullerton (1984) discuss each measure and their advantages and disadvantages. METR calculations are designed to measure the tax cost on marginal incentives to hire labor or employ capital. However, they are calculated formulaically using the net present value of income, tax credits, and tax deductions. Because of this they require numerous assumptions about firm financing, asset purchase decisions, and depreciation (Collins and Shackelford, 1995). In addition, the calculation must explicitly choose which provisions of the tax code (i.e., which deductions and tax credits) to include and how to model them. As a practical matter, this will cause METRs to miss the cumulative effect of numerous small or difficult to model features that are not included.

AETRs are calculating empirically by dividing taxes paid by the base of economy activity taxed. Because it is calculated from actual tax payments, it avoids the problems METR calculations face of having to make numerous assumptions and being forced to pick and choose the features of the tax code to include. However, the AETR measures the average tax rates on all investments as opposed to finding the tax rate on the marginal investment. It thus reflects the total burden of taxation instead of marginal incentives (Collins and Shackelford, 1995).


<table>
<thead>
<tr>
<th>Sector</th>
<th>Corporate Income Taxes</th>
<th>Other Production Taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and Gas Extraction</td>
<td>42,715</td>
<td>227,965</td>
</tr>
<tr>
<td>Petroleum and Coal Products</td>
<td>213,416</td>
<td>29,153</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>213,416</td>
<td>29,153</td>
</tr>
<tr>
<td>Pipeline Transportation</td>
<td>4,249</td>
<td>20,723</td>
</tr>
<tr>
<td>Fossil Fuel Production¹</td>
<td>260,381</td>
<td>277,842</td>
</tr>
<tr>
<td>All Sectors</td>
<td>4,107,379</td>
<td>11,075,086</td>
</tr>
</tbody>
</table>

Source: Author’s calculation from BEA US Input-Output Accounts and NIPA Table 6.18D. Notes: (1) Fossil fuel production is defined as oil and gas extraction, petroleum and coal products manufacturing, and pipeline transportation.

C.2 Methodology

In this analysis, I calculate tax rates using the AETR method. I do so because the information required to credibly calculate METRs simply does not exist for two critical areas: the types of capital whose tax treatment are changing in the budget and the production taxes

58 See CBO (2006) for a more detailed description of the general method used to calculate METRs.
59 The AETR method is certainly not without its own drawbacks. See Fullerton (1984) for a discussion of the problems of AETRs.
such as excise, severance, and sales taxes. But a problem which remains in the AETR method is the distribution of the tax burden. If producers are able to forward shift the burden onto consumers, then tax payments should be divided by total consumer payments, the total value of output. Alternatively, if a tax would be backwards shifted onto labor or capital, payments to those factors are the base that should be used. But who bears the burden of a tax cannot be answered without using a general equilibrium model. So I leave that analysis to section 3 and here present results under both assumptions, one using the total value of output assuming full forward shifting, and one using total factor payments assuming full backwards shifting.

My two main data sources are the Use of Commodities by Industries after Redefinitions tables for 1998-2009 in the US Input-Output accounts from the Bureau of Economic Analysis (BEA) and two tables from the National Income and Product Accounts (NIPA), also by the BEA. I use table 3.4ES: Current-Cost Depreciation of Private Fixed Assets by Industry and table 6.18D: Taxes on Corporate Income by Industry. The average effective tax rate for a selection of energy sectors and the whole economy is calculated by dividing total tax payments by both the value of output and factor payments. The average effective tax rate on firm capital for those same sectors is calculated by dividing corporate income tax payments by sector capital income.

There are a number of important definitions and assumptions related to the calculation of AETRs. Total tax payment equals taxes on production and imports plus state, local, and federal corporate income taxes minus subsidies. Taxes on production and imports include taxes on the product delivery or the sale of products and taxes on the ownership of assets used in production, such as federal excise, state and local sales taxes, and local real estate taxes. Corporate income taxes include those taxes at the federal, state, and local level. Factor payments are equal to net operating surplus plus compensation of employees, plus taxes on production and imports, less subsidies. Due to data limitations, capital taxes include firm level taxes but do not include individual level capital income taxation such as that on capital gains, dividends, or income from pass-through entities.

60 In an alternative specification, I instead use corporate income tax data from the Internal Revenue Service Statistics of Income Tax Stats on the Returns of Active Corporations by Minor Industry. These results show a smaller difference between all industries and the selected fossil fuel producers, but still indicate a lower tax rate for other industries than fossil fuels. However, this data set does not include state and local income taxes and has one less year of data. Full results are available upon request.

C.3 AETR Estimates

Table 14 presents AETRs on capital for firms in selected sectors averaged over the years 1998-2009. Firm capital tax rates for oil and gas extraction and pipeline transportation are lower than the economy average but much higher for petroleum and coal products manufacturing. Firm capital AETRs for fossil fuel production as a whole are higher than those of other sectors because petroleum and coal products manufacturing has more capital and faces higher tax rates than the other fossil fuel producing sectors.

Table 14: Firm Average Effective Tax Rates on Capital from Corporate Income Taxes by Sector, 1998-2009 (Percent)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Capital AETR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and Gas Extraction</td>
<td>4.5</td>
</tr>
<tr>
<td>Petroleum and Coal Products Manufacturing</td>
<td>21.1</td>
</tr>
<tr>
<td>Pipeline Transportation</td>
<td>6.1</td>
</tr>
<tr>
<td>Fossil Fuel Production</td>
<td>12.8</td>
</tr>
<tr>
<td>All Sectors</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Source: Author’s calculation from BEA US Input-Output Accounts and NIPA Tables 3.4ES and 6.18D.

Table 15 presents AETRs of all taxes for energy and other sectors averaged over the years 1998-2009. This table includes all firm level taxes, i.e. not just capital taxes but production taxes as well. Since these taxes could be forward shifted onto consumers or backwards shifted onto factors, or somewhere in between, I calculate AETRs under both assumptions. The factor income base assumes full backward shifting onto factors and divides total firm taxes paid by labor and capital income. The value of output base assumes full forward shifting onto consumers and divides total firm taxes paid by the value of output.

As before, AETRs for fossil fuel production are higher than those of other sectors on both a factor income base and a value of output base. Additionally, this result obtains not just for fossil fuel production as a whole, but the fossil fuel producing subsectors individually as well. With the exception of petroleum and coal products manufacturing on a value of output base, AETRs are higher for all fossil fuel producing firms than the economy as a whole.

This analysis shows that the AETR on fossil fuels producing firms is higher than the AETR for firms in other sectors under all three specifications. So for this measure of taxation, fossil fuel production is more heavily, not less, taxed than other sectors.

However, it needs to be emphasized that this is a single measure of taxation and not a full

\[ \text{Appendix C.4} \] investigates if these results are driven by a particular industry or year but concludes that they are not.
Table 15: Average Effective Tax Rates of All Firm Taxes by Sector, 1998-2009 (Percent)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Factor Income Base</th>
<th>Value of Output Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and Gas Extraction</td>
<td>19.3</td>
<td>12.1</td>
</tr>
<tr>
<td>Petroleum and Coal Products</td>
<td>20.0</td>
<td>5.2</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>16.7</td>
<td>7.5</td>
</tr>
<tr>
<td>Pipeline Transportation</td>
<td>19.5</td>
<td>7.4</td>
</tr>
<tr>
<td>Fossil Fuel Production</td>
<td>10.8</td>
<td>5.9</td>
</tr>
</tbody>
</table>

Source: Author’s calculation from BEA US Input-Output Accounts and NIPA Tables 3.4ES and 6.18D.

account of all ways in which fossil fuel production could be favored. For example, the income and taxes used in the AETR calculation do not only come from corporations. But the proposed tax changes deal primarily with corporations. This analysis does not rule out the possibility that corporate form firms are less taxed than other sectors, while non-corporate firms and the average fossil fuel firm is more taxed. In addition, although the AETR includes all firm level taxes, some firms, (e.g., sole proprietorships and partnerships) actually have their income taxed at the personal level. These tax payments are not included in this measure of AETR.

C.4 Average Effective Tax Rates by Industry and Year

Although the AETR on capital, value of output, and total income are higher in fossil fuel production than other sectors, several readers have expressed concerns that these results may be driven by a few outlier industries or years. For example, years in the sample where oil company profits were extremely high might make the average tax rate over the entire period much higher than the median yearly rate. Tables 16 and 17 investigate this possibility by breaking results down by industry and year.

The most notable outliers in Table 16 are the capital tax rates of management of companies and enterprises and real estate rental and leasing. Real estate rental and leasing is especially interesting because there is an extremely large capital stock in housing but this sector is typically non-corporate and thus would be missed in my measure of capital taxation. However, the removal of these two sectors does not change results. Removing real estate increases the capital AETR of all industries to 10.6 percent. Removing management of companies and enterprises reduces the capital AETR of all industries to 6.7 percent. In both cases, the capital AETR of fossil fuel production of 12.8 percent remains higher than the all industry average.

Table 17 indicates that results are not driven by any particular year. AETR are higher for
Table 16: Average Effective Tax Rates by Industry for 1998-2009 (Percent)

<table>
<thead>
<tr>
<th>Industry</th>
<th>Capital Value of Factor</th>
<th>Output Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management of Companies and Enterprises</td>
<td>138.7</td>
<td>12.7</td>
</tr>
<tr>
<td>Petroleum and Coal Products Manufacturing</td>
<td>21.1</td>
<td>5.2</td>
</tr>
<tr>
<td>Finance and Insurance</td>
<td>20.2</td>
<td>6.6</td>
</tr>
<tr>
<td>Retail Trade</td>
<td>15.8</td>
<td>17.4</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>14.8</td>
<td>2.9</td>
</tr>
<tr>
<td>Fossil Fuel Production</td>
<td>12.8</td>
<td>7.4</td>
</tr>
<tr>
<td>Mining</td>
<td>9.5</td>
<td>5.8</td>
</tr>
<tr>
<td>Wholesale Trade</td>
<td>9.2</td>
<td>17.5</td>
</tr>
<tr>
<td>Utilities</td>
<td>8.9</td>
<td>14.4</td>
</tr>
<tr>
<td>Information</td>
<td>8.4</td>
<td>6.0</td>
</tr>
<tr>
<td>All Industries</td>
<td>7.5</td>
<td>5.9</td>
</tr>
<tr>
<td>Educational Services</td>
<td>7.2</td>
<td>3.4</td>
</tr>
<tr>
<td>Pipeline Transportation</td>
<td>6.1</td>
<td>7.5</td>
</tr>
<tr>
<td>Transportation and Warehousing</td>
<td>5.4</td>
<td>3.6</td>
</tr>
<tr>
<td>Oil and Gas Extraction</td>
<td>4.5</td>
<td>12.1</td>
</tr>
<tr>
<td>Accommodation and Food Services</td>
<td>4.1</td>
<td>7.1</td>
</tr>
<tr>
<td>Construction</td>
<td>3.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Administrative, Support, and Waste Management</td>
<td>3.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Health Care and Social Assistance</td>
<td>3.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Professional, Scientific, and Technical Services</td>
<td>1.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Arts, Entertainment, and Recreation</td>
<td>1.6</td>
<td>7.8</td>
</tr>
<tr>
<td>Other Services, Except Government</td>
<td>0.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Agriculture, Forestry, Fishing, and Hunting</td>
<td>0.7</td>
<td>-2.6</td>
</tr>
<tr>
<td>Real Estate and Rental and Leasing</td>
<td>0.3</td>
<td>8.1</td>
</tr>
</tbody>
</table>

Table 17: Average Effective Tax Rates by for Select Industries for 1998-2009 (Percent)

<table>
<thead>
<tr>
<th>Year</th>
<th>Fossil Fuel Production</th>
<th>All Industries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capital Value of Factor</td>
<td>Capital Value of Factor</td>
</tr>
<tr>
<td></td>
<td>Output Income</td>
<td>Output Income</td>
</tr>
<tr>
<td></td>
<td>Factor Income</td>
<td>Factor Income</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>5.8</td>
<td>11.3</td>
<td>15.1</td>
<td>17.4</td>
<td>17.4</td>
<td>15.2</td>
<td>9.8</td>
<td>6.0</td>
<td>10.7</td>
<td>17.5</td>
<td>10.2</td>
<td>7.7</td>
</tr>
<tr>
<td>Value of Output</td>
<td>6.3</td>
<td>6.7</td>
<td>7.9</td>
<td>8.6</td>
<td>8.9</td>
<td>8.8</td>
<td>7.1</td>
<td>5.6</td>
<td>7.0</td>
<td>7.1</td>
<td>6.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Factor Income</td>
<td>26.7</td>
<td>27.6</td>
<td>31.0</td>
<td>31.9</td>
<td>29.6</td>
<td>27.0</td>
<td>23.4</td>
<td>26.5</td>
<td>25.0</td>
<td>33.1</td>
<td>32.5</td>
<td>26.8</td>
</tr>
</tbody>
</table>
fossil fuel production than the all industry average on all measures and years with only one exception: capital in 1998.

D Cost and Expenditure Function Parameters for the Energy Model

This section lists the parameters estimated for the firm cost and consumer expenditure functions in the energy model. These parameters are from the baseline regression specification that uses iterated three-stage least squares with one period lagged prices as instruments. This appendix is available online at [http://barbe.blogs.rice.edu/files/2014/03/Online-Appendix-2.pdf](http://barbe.blogs.rice.edu/files/2014/03/Online-Appendix-2.pdf)

E Full Regression Summary Statistics

This section lists the full summary statistics for the baseline regressions used to parametrize the energy model. These summary statistics are for the baseline regression specification that uses iterated three-stage least squares with one period lagged prices as instruments. This appendix is available online at [http://barbe.blogs.rice.edu/files/2014/03/Online-Appendix-2.pdf](http://barbe.blogs.rice.edu/files/2014/03/Online-Appendix-2.pdf)