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

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Working Paper: November 2013

Abstract

This paper constructs a new general equilibrium model of the United States economy designed to analyze energy tax policies. Existing models in the literature fall into two groups: general equilibrium models 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. The new model is able to analyze the inefficiencies caused by energy taxation: production and consumption inefficiencies, inefficiencies related to resource rents, and those related to externalities. The 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 raise revenue by imposing 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 unclear. Some provisions move toward neutrality in taxation as advocated in the literature while others do not. The paper also analyzes relative levels of taxation and shows that, taking into account all forms of taxation rather than only income taxes, fossil fuel production is on average taxed more highly than other industries. Second, in comparison to a uniform tax increase that would raise the same amount of revenue, the proposal would have positive – and to some extent unexpected – effects on the US economy. The energy tax increases of the proposal lead to higher household welfare than would occur under a uniform capital tax increase but also would increase the production of fossil fuels, as general equilibrium effects increasing demand more than offset the negative effects of tax-reform-induced increases in the cost of capital in the energy industry. Third, considering general equilibrium effects and allowing for flexible substitution in both inputs and consumption goods significantly alter the predicted impact of the proposal and are thus necessary to accurately predict the effects of energy taxes on the energy industry and the economy. A model that neglects either of these two factors would underestimate the welfare gains from the proposal and not capture the net increase in fossil fuel production. In total, these results show that the budget proposal increases economic efficiency and that general equilibrium models with flexible substitution provide an improved model of energy taxation.

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Contents

1 Introduction

Models in the energy taxation literature fall into two general categories. 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. This paper builds a general equilibrium model with the most important features of both approaches: this model has endogenous supply of the energy resource in a general equilibrium model that allows for flexible substitution by firms across inputs and by consumers across goods. The resulting model allows a comprehensive analysis of the inefficiencies caused by energy taxes; these inefficiencies include production and consumption inefficiencies attributable to tax-induced price distortions, any inefficiencies that arise from the taxation of the returns to energy resources, and the inefficiencies due to the externalities associated with the production of fossil fuels.

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.[1] When a relatively highly taxed good is an input in production and a consumption good, firms and consumers who act to minimize their post-tax private costs of production or the costs of achieving their utility level will not minimize their pre-tax or social costs, leading to productive and consumptive inefficiency.

Substitution toward or away from energy inputs or final goods is the cause of the productive and consumptive inefficiencies due to energy taxes. Therefore, accurate modeling of producer and consumer substitution is critical to determining the magnitudes of such substitutions and the efficiency loss. 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 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).[2] By comparison, Altig et al. (2001), Fullerton and Rogers (1993),

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[1] The 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.

[2] Nested 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).

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 I follow. Jorgenson and Yun (2001) and my model 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).[3]

The second source of energy tax inefficiency is the tax treatment of resource rents. If the energy resources have perfectly inelastic supply, then their factor payments would be economic rents and taxing them would be non-distortionary. In such a case, non-distortionary resource rent taxes are 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 literature contains many 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 energy resources. Dasgupta, Heal, and Stiflitx (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 supply 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 externalities. 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

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[3]See Section 3.4.1 for a detailed description of the translog cost function.

optimal level of the activity. Of the models listed so far, only Paltsev et al. (2005) and Babiker et al. (2008) incorporate these externalities. My model does as well by including disutility from fossil fuel externalities in the utility function.

In this paper, I construct a CGE model of US energy taxation that includes all three sources of tax inefficiency. 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) functional forms. There are 22 production sectors, with each producing a single output using capital, labor, and 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 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 check to make sure 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 discussed above, 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 so that energy resources either accrue resource rents or simply receive a normal rate of return. I vary this supply elasticity from 0.1, where energy resources have higher rents than capital, to 0.5, where rents are the same for the resource and capital, in order to test the importance of resource rents. And finally, negative externalities from greater fossil fuel production are included in the utility function.

Beyond these innovations for improved modeling of energy taxation, the CGE model used in this paper 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]

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[4]An isoelastic function has the form $f(x) = kx^r$ and has elasticity r.

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.

I use this CGE model to analyze energy tax changes in the president's fiscal year 2014 budget proposal. The president's budget proposes to make the tax code more neutral through the elimination of tax preferences for fossil fuel production. However, thus far the arguments in favor or against these changes have been descriptive judgments based on principles of neutral taxation: the actual economic effects of the proposal have not been estimated. I use my model to estimate these effects.

The organization of the paper is as follows: in Section 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. In Section 3, I present the details of the general equilibrium model: the equations used to define the supply and demand of commodities, the data used to parametrize these equations, and other assumptions. I calculate the current tax rates facing fossil fuel production, taking into account both income taxes and various production-based taxes. I then use the model to simulate the macroeconomic effects of the budget proposal, relative to a reform that raises the same amount of revenue with a uniform increase in capital taxes. I also calculate the social cost of the carbon dioxide emissions increase attributable to the budget proposal. Section 4 discusses the results of the simulations and Section 5 summarizes the findings and concludes.

2 Budget Proposal

2.1 Proposal Overview

The primary analysis in this paper is accomplished through simulations of the model described in Section 3. However, in this section I describe the provisions of the president's 2014 budget proposal and compare them to the treatment that would be applied in a neutral tax system. I also evaluate some subtle features of the proposal that cannot be analyzed directly within the structure of the general equilibrium model. This section lists the provisions, describes current law, discusses what each provision will and will not change relative to current law, and

Table 1: Revenue Estimates of Provisions of the President's 2014 Budget for 2013-23 ($ millions)

Provision	JCT (2013)	Treasury (2013)
Repeal LIFO inventory accounting for all sectors	78,299	80,822
Repeal the domestic manufacturing deduction for fossil fuels	19,881	17,856
Repeal expensing of intangible drilling costs	13,698	10,993
Repeal percentage depletion for oil and gas	11,118	10,723
Reinstate Superfund excise taxes[1]	8,153	8,032
Modify tax rules for dual capacity taxpayers	7,896	10,964
Increase Oil Spill Liability Trust Fund financing rate	1,863	1,058
Increase geological and geophysical amortization period	1,251	1,363
Repeal the capital gains treatment of coal royalties	603	432
Repeal percentage depletion for coal and other hard mineral fossil fuels	595	1,982
Repeal expensing of coal exploration and development	591	432
All other fossil fuel specific provisions	270	181
Total	144,218	144,838

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).

then compares current law and the proposed changes to the treatment of these issues under a neutral tax system.

The Obama administration has made a standard tax neutrality argument to justify the budget's tax changes. Table 1 lists revenue estimates of these changes, as calculated by the Department of the Treasury (2013), hereafter Treasury, and the Joint Committee on Taxation (2013), hereafter JCT. The president has stated that because of these provisions, investment in fossil fuel production faces a lower effective tax rate than investment in other sectors of the economy (Office of the Press Secretary, 2012).[5] The Treasury and the JCT have also stated that, under current law, the US federal income tax code contains tax preferences that favor the production of fossil fuels (Treasury, 2013; JCT, 2012).[6] Treasury argues reduced energy security[7], higher carbon emissions, and higher taxes on the rest of the economy are consequences of this distortion.

A tax code is neutral if it does not influence economic choices such as which inputs or technologies are used for production, the allocation of investment across assets and industries, how

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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.1 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.

firms are organized, and how investments are financed. In particular, tax neutrality is necessary for production efficiency and consumption efficiency. Tax neutrality is a useful concept because previous work has shown that under certain assumptions, both production and consumption neutrality are efficient. For example, Diamond and Mirrlees (1971) derive a "production efficiency theorem" which develops the conditions under which production non-neutralities are undesirable and Atkinson and Stiglitz (1976) derive conditions under which consumption good differentials are unnecessary to accomplish redistributive goals.[8] Neutrality is thus a proxy for efficiency that is easier to measure.

However, there is still disagreement among experts on the specific details of tax neutrality as well. Scholars differ in their evaluation of which tax credits, deductions, or tax rates are neutral. In order to evaluate whether a particular provision in the budget is neutrality-enhancing or neutrality-reducing, for each provision I compare what the previous literature has argued is the neutral treatment to the treatment specified in the budget proposal.

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

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.[9]

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. In order to use LIFO for tax purposes, a firm must also use LIFO for financial accounting purposes (Treasury 2013).

Although LIFO accounting is not unique to firms that produce fossil fuels, LIFO is disproportionately used by firms in the energy sector. 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). Additionally, energy companies

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[8]See also Hammond (2000) and Hellwig (2008).

[9]See 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.

account for more than 82 percent of the LIFO reserves of all companies on the S&P 500 Index (Przybyla, 2011).

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 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.

The president'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 satisfying these goals by allowing firms to choose between FIFO indexed for inflation or LIFO.[10] However, 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.

2.3 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

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[10]Kleinbard, Plesko, and Goodman (2006) notes that inflation affects all capital investment, not just inventories, and thus should be dealt with in a systematic manner instead of through LIFO as a piecemeal solution affecting only inventories would favor investment in one form over another. However, a neutral tax system would allow inflation indexation for both inventories and capital investment.

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.

2.4 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).[11]

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).[12] Although the expensing of intangible drilling costs is not exclusively for oil and natural gas but also 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

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[11]Integrated oil and gas companies refer to oil and gas producers that conduct production, refining, and retail sales activities. (JCT 2012).

[12]Typically, depreciable assets are used to recover depletable assets (JCT 2012).

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.[13] 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.[14]

2.5 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 the 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.[15]

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).[16]

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 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).

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[13]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.

[14]See CBO (2011) for further discussion of this issue.

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

[16]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).

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 deprecation rate would be. But using the rate at which minerals are removed from the property as the deprecation 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 Table 16 in Section C.3, in aggregate these production taxes average $20 billion for oil and gas extraction 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.[17]

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 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. But it also reduces the neutrality of the code by eliminating a deduction that offsets other distortionary taxes and through favoring

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[17]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.

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.

2.6 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.[18] 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 and also government oil spill prevention and response programs (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.[19]

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).

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

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[18]The excise tax rate is also called the financing rate.

[19]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.

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 take 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).[20]

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. For the Deepwater Horizon oil spill, BP set up a $20 billion fund that had paid $4.7 billion as of July 2011, far exceeding the Oil Spill Liability Trust fund's $1 billion cap (Yost,

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[20]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.

2011). 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 spill 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.

2.7 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.[21]

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

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[21]See Probst et al. (1995) for more detail on the Superfund program in general and CBO (2011) for reform options.

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.

2.8   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.[22] 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.[23]

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[22]Treasury Regulation section 1.901-2(a)(2)(i).
[23]Treasury Regulation section 1.901-2(a)(2)(ii)(A).

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.[24] [25]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.[26] 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).[27]

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 credible 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 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

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[24]Treasury Regulation section 1.901-2A(c).

[25]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).

[26]Treasury Regulation section 1.901-2A(c)(2)(i).

[27]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 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.[28] 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.

2.9 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.

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.

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[28]Kleinbard (2007) and Gravelle (2012) advocate residence-based taxation. Desai and Hines (2004) argues in favor of territorial-based taxation. CBO (2013) reviews different policy options.

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 .0751 and lists a service life of 12 years.[29] 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.

2.10 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.[30]

2.11 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 re-

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[29]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).

[30]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

capture 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).[31]

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 .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 Model

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.[32] PE models focus on resource supply decisions by firms and take a large number of different approaches such as neoclassical (Dasgupta, Heal, and Stiflitx, 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 (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.

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[31]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).

[32]See Lund (2009) or Smith (2012) for comprehensive reviews of the literature on modeling energy taxation.

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. The model constructed in this paper is most closely related to the energy focused CGE models of Paltsev et al. (2005), Babiker et al. (2008), Jorgenson and Yun (2001), and Wilcoxen (1988).[33] Paltsev et al. (2005) and Babiker et al. (2008) examined climate change policies using CGE models with an exogenously supplied energy resource. Although Jorgenson and Yun (2001) and Wilcoxen (1988) have no energy resource, these models had flexible substitution. They feature translog producer cost functions and consumer expenditure functions whose parameters 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 Overview

I construct a 22 sector steady-state CGE model of the US economy with flexible substitution across production inputs and consumer goods and endogenous resource supply. As discussed above, this model combines the advantages of the CGE and PE methods of energy tax analysis and incorporates the three main efficiency effects of energy taxation. In this section, I summarize the most important features of the model: the translog cost and expenditure functions, capital and labor supply, commodity demands, regression estimation of the parameters, and the modeling of the budget proposal. The remaining details are presented in Appendix B.

In the model, the cost function for an industry relates the cost of producing the industry's output to the cost of the industry's inputs – capital, labor, and all the outputs of the industry

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[33]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).

Figure 1: Commodity Flows
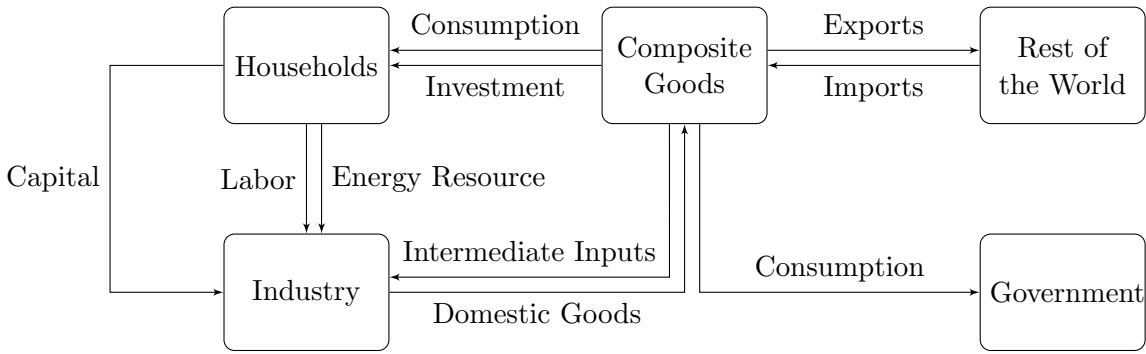
cost functions. The model utilizes a translog cost function for each industry, following Jorgenson and Yun (2001) and Wilcoxen (1988). Although the functional form of the translog cost function is quite complex, its key features can be described simply: it allows different degrees of substitution between all inputs, changes in the relative importance of particular inputs over time due to technological progress, and changes in total factor productivity in each industry due to technological progress. 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.

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

I perform a series of regressions to estimate the values of the parameters that define the relationships in the cost functions. Calibration of the model is thus generally avoided, although several parameter values that cannot be estimated are taken from the literature. Regression estimation of most parameters rather than calibrating the model to values taken from a single

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[34]Note that this assumption is made implicitly in any model that aggregates all workers into a single type of labor.

year has important advantages. In particular, calibrated parameter values are sensitive to the idiosyncratic conditions of the year of calibration. By contrast, 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 addressed 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 U.S. 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 Tables of the Use of Commodities by Industries for 1997-2010 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 and SIC.

In order to determine the effects of the president's budget proposal, the economy under the proposal must be compared to the state of the economy under an alternative policy. The most obvious alternative is current law tax rates. However, using that as an alternative would require information about how the additional revenue raised under the budget proposal is spent. Unfortunately, the budget proposal does not specify how the new government revenue will be spent.[35]

To simplify the comparison, I instead compare the president's fiscal year 2014 budget proposal to a policy that raises the same amount of revenue by increasing capital taxes at a uniform rate on all sectors.[36] In order to avoid choosing a spending policy, I assume that the equal amounts of additional tax revenue raised under both tax regimes are spent in a manner that has no impact (e.g., the revenues are spent on public goods that are separable in the individual utility function). A uniform increase in capital tax rates was chosen because most of the revenue of the budget proposal comes from capital tax rate increases for fossil fuel production. Taxation under current law is modeled as a tax on capital, a tax on labor, a tax on energy

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[35]I could arbitrarily decide how the revenue would be spent but this would turn the analysis into as much of a judgment of the chosen spending policy as an analysis of the tax policy.

[36]Note that a uniform increase in capital taxes is not the same as a uniform increase in the corporate income tax rate since the former applies equally to all industries and assets.

Table 2: Literature and Data Parameters and Values in Baseline Specification

Symbol	Definition	Value	Source
$\theta_{capital}$	Elasticity of capital supply with respect to capital rental rate	0.5	Gunning, Diamond, and Zodrow (2008)
θ_{labor}	Elasticity of labor supply with respect to wage rate	0.2	McClelland and Mok (2012)
$\theta_{resources}$	Elasticity of resource supply with respect to resource price	0.5	Section 3.3
θ_{Arm}	Armington elasticity of substitution between domestic and imported goods for fossil fuel production[1]	23	Balistreri, Al-Qahtani, and Dahl (2010)
θ_{Arm}	Armington elasticity of substitution between domestic and imported goods for sectors other than fossil fuel production[1]	4	Rutherford and Paltsev (2000)
θ_{export}	Own price elasticity of export demand	-1	Senhadji and Montenegro (1999)
θ_r	Elasticity of substitution between resource and KLEM	4	Section 3.3
$\tau_{capital}$	Effective tax rate on capital	Varies[2]	Section 3.5.1
τ_{labor}	Effective tax rate on labor	0.316	CBO (2005)
$\tau_{resources}$	Effective tax rate on energy resource	Varies[2]	Section 3.5.1
$\tau_{production}$	Effective tax rate on production	Varies[2]	Section 3.5.1

Notes: (1) Fossil fuel production is defined as the industries of oil and gas extraction and coal and petroleum products manufacturing (refining).
(2) This effective tax rate is calculated for each sector individually.

reserves, and production taxes on output.

3.3 Parameter Definitions and Notation

This section summarizes the most important parameters in the model. There are two types of parameters in the model: endogenous and exogenous. Endogenous variables are those explained by the model such as price p, quantity q, and total expenditure u can be found in Appendix B.1. Exogenous variables come from the regression, literature, or data. Regression estimated parameters are exogenous to the CGE model but are estimated by the regressions described in Section 3.4.2. Literature and data parameters are those not calculated by the model or the regression. The literature or data that produces these parameters are described in this section.

Table 2 provides 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. A world market for energy products exists and 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, a 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. Then, in Section 4, I conduct sensitivity tests using alternative values of this parameter.

The third noteworthy parameter is the elasticity of energy resource supply since varying this elasticity determines extent of resource rents. A value of zero implies that all returns to the resource are economic rents. A value of 0.5 is the same as the elasticity for capital, and indicates that the resource has the same level of economic rents as capital. This parameter is varied in the sensitivity tests in order to examine the importance of resource rents.

3.4   Firm Cost and Consumer Expenditure Functions

3.4.1   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. [37] The tier structure used to nest the cost functions is shown in the tree in Figure 2.

Figure 2: Tiers for the Translog Cost Function for Firm Production
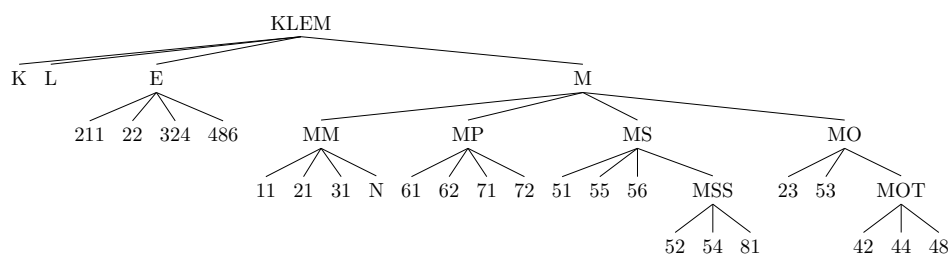
Notes: K is capital, L is labor, and N is non-competing imports. KLEM is the top tier output for the translog cost function but not the entire model, see Section B.3 for details. Numbers give the NAICS code of the respective sector. All other letters are the names of aggregate outputs.

An aggregate output and its components inputs will be called a "node" of the structure. The top translog node has a sector's KLEM output created from capital (K), labor (L), energy

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[37]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.

(E), and materials (M), while 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

$$
ln(c_{xot}) = \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \beta_{xij}^{substitution} ln(p_{xit}) ln(p_{xjt}) + \sum_{i=1}^{N} \beta_{xi}^{share\ constant} ln(p_{xit})
$$
$$
+ \sum_{i=1}^{N} \beta_{xi}^{share\ trend} ln(p_{xit}) t + \beta_{xo}^{cost\ trend} t + \beta_{xo}^{cost\ constant} \tag{1}
$$

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, $ln(p_{xit})$ is the log of the price of input i at time t to industry x, and t is measured in years.[39] The variables $\beta_{xij}^{substitution}$, $\beta_{xi}^{share\ constant}$, $\beta_{xi}^{share\ trend}$, $\beta_{xi}^{cost\ trend}$, and $\beta_{xo}^{cost\ constant}$ for the inputs i and j are the parameters to be estimated at this node.

Intuitively, $\beta_{xij}^{share\ trend}$ defines how use of input i responds to changes in the price of input j for industry x. The variable $\beta_{xi}^{share\ constant}$ 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 $\beta_{xi}^{share\ trend}$ defines how much the value share of input i changes in one year for industry x if input prices do not change. The variable $\beta_{xo}^{cost\ trend}$ is a productivity parameter that defines how much the cost of output changes over time for industry x. The variable $\beta_{xo}^{cost\ constant}$ 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 $\beta_{xo}^{cost\ trend}$ or

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[38]The KLEM output is not the final output used by consumers or firms. Section B.3 details how KLEM is combined with the energy resource and inputs 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 a particular node according to Figure 2. It varies across nodes but is the same at any particular node across industries.

$\beta_{xo}^{cost\ constant}$ when $o \neq$ KLEM. I therefore constrain them to be 0 when $o \neq$ KLEM.

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 $\beta_{xo}^{cost\ trend}$ or $\beta_{xo}^{cost\ constant}$ for consumers even at node KLEM. I therefore constrain them to be 0 for consumers at all nodes.

3.4.2 Translog Regression

In this section, I estimate and examine Equation 1 for each output and industry through a series of regressions and tests. 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. This 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. 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 calculate several test statistics, estimate two alternative specifications, and perform a Monte Carlo simulation. These methods indicate that model results are not affected by the choice of instruments or the fact that some excluded instruments are weakly correlated with the included endogenous variables.

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.[40] [41] The R^2 is calculated differently for commodity KLEM. For most commodities, the R^2 values of the cost share equation are presented because no cost equation exists. For commodity KLEM, the R^2 values from the cost equation are presented and no cost share equation exists. The average R^2 value is 0.993 for KLEM. Because KLEM is basically the final domestic cost for a sector, this high R^2 shows that the predictive power of the model as a whole is quite high.[42]

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[40]Full regression parameter estimates and summary statistics are presented in the Online Appendix at `http://barbe.blogs.rice.edu/files/2013/11/Online-Appendix-1.pdf`.

[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]For industries that do not produce fossil fuels, KLEM cost is exactly the domestic cost. However, for fossil

Table 3: Regression R^2 Statistics

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

Notes: (1) For commodity KLEM, the mean and standard deviation of the R^2 values from the cost equation are presented and 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

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

I test the validity of the instrumental variable specification using both underidentification and weak identification tests (Table 4). A Lagrange multiplier version of the Anderson canonical correlation test statistic is calculated in order to test for underidentification (Anderson, 1951).[43] 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. The Online Appendix at `http://barbe.blogs.rice.edu/files/2013/11/Online-Appendix-1.pdf` indicates that these p-values are very high for consumers but very low for industries. Therefore underidentification may be a problem for the regression specification.

Results for the second tests also suggests that the instruments are weak. For this test, I calculate the Cragg-Donald statistic in column 4 (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.[44] 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

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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.

[43]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."

[44]This value is for the test based on two-stage least squares bias and a .30 maximal bias of instrumental variables relative to ordinary least squares.

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 10 of Section 4.2. However, these alternative specifications give very similar predictions to the baseline for all economic variables. 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 12 discussed in Section 4.2, and demonstrate that model results are not affected by any such instability.

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 instability in parameters results from weak instruments all do not affect results. The regression specification provides robust parameter values to the model.

3.5   Taxation

This section describes the tax rates used in the model, both for current law and the rate changes implied by the energy provisions in 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, the rate for capital and resource taxes are determined partly from data and partly from the literature, and the tax rate for labor is taken from the literature. The tax rate changes under each provision of the budget proposal are determined by assigning a base to each provision and then calculating the rate change 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.

3.5.1   Current Law Tax Rates

In this section, I calculate current law tax rates on the capital, labor, energy resource, and production and compare rates for fossil fuel production and other sectors. The values of the tax rates are themselves necessary for use in the CGE model. However, comparison of the tax rates

between sectors also serves a secondary purpose: evaluation of the neutrality of the budget proposal. Supporters of the budget proposal contend that tax rates are lower for fossil fuel production than other sectors and that raising effective rates for fossil fuel production would therefore make the tax code more neutral. I evaluate that claim in this section by comparing AETRs for firms in different sectors.

Current law tax rates are calculated using data from a number of sources. The capital tax rate is equal to the sum of firm and personal capital tax rates. The rates for the firm-level capital taxes and production taxes vary by industry and are taken from the average effective tax rate (AETR) results presented later in this section.[45] Personal level capital taxes are 12.5 percent so that the total capital tax rate for the entire economy equals the 20 percent rate estimated by Mackie (2002). $\tau_{resource}$ is equal to the value of $\tau_{capital,x}$ where $x =$ the oil and gas extraction industry. The tax rate on labor income is set equal to 31.6 percent following CBO (2005). The production tax rate for each industry is equal to the the AETR using all taxes except capital taxes on a value of output base. The tax rate on the energy resource is equal to the total capital tax rate for oil and gas extraction.

Table 5 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 5: Firm Average Effective Tax Rates on Capital from Corporate Income Tax by Sector, 1998-2009 (Percent)

Sector	Capital AETR
Oil and gas extraction	4.5
Petroleum and coal products manufacturing	21.1
Pipeline transportation	6.1
Fossil fuel production	12.8
All sectors	7.5

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

Table 6 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

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[45]Details on the AETR methodology and a literature review of alternate methodologies and results are presented in Appendix C.

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.

Table 6: Firm Average Effective Tax Rates of All Taxes by Sector, 1998-2009 (Percent)

Sector	Factor Income Base	Value of Output Base
Oil and gas extraction	19.3	12.1
Petroleum and coal products manufacturing	20.0	5.2
Pipeline transportation	16.7	7.5
Fossil fuel production	19.5	7.4
All sectors	10.8	5.9

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

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.[46] So for this measure of taxation, fossil fuel production is more heavily, not less, taxed than other sectors. This indicates that the tax code is not neutral, but that it is biased against, not in favor of, fossil fuel production.

3.5.2 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 provision to apply to a particular tax base (capital or production) for a particular sector or set of sectors, as shown in Table 7. 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

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[46]Appendix C.4.2 investigates if these results are driven by a particular industry or year but concludes that they are not.

Table 7: Tax Bases for Provisions in Budget Proposal

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

by each provision for each base for each sector are added together to provide a cumulative rate for all provisions.

4   Results

In this section, I use the computable general equilibrium model described in Section 3 to examine the effects on fossil fuel production and on the rest of the US economy of the changes to fossil fuel taxation proposed in the president's 2014 budget. I calculate the value of economic variables under the proposal and compare them to their value under an equal revenue increase in capital income tax rates. I find that the budget proposal is efficiency enhancing and that, due to general equilibrium increases in energy demands in other industries, it increases fossil fuel production. Sensitivity tests show that these results are robust to a variety of changes to the model. These results confirm the importance of general equilibrium modeling that allows flexible input and consumption good substitution for analyzing energy taxes.

4.1   Baseline Results

Table 8 illustrates the effects of implementing the budget proposal compared to a revenue-neutral uniform increase in capital tax rates. The economic efficiency of the proposal is measured using the welfare of the representative household. Under the budget proposal, household welfare would increase by 1.04 percent. In addition, other economic variables such as the capital stock,

Table 8: Macroeconomic Effects of Proposal

Variable	Percent Change in Variable
Welfare	1.04
Capital Stock	0.43
Employment	0.07
Consumption	0.90
Output	0.32
Capital Rental Rate[1]	0.86
Labor Wage Rate[1]	0.33

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

employment, household consumption, domestic output, wages, and the return to capital would also all increase under the budget proposal.

The explanation for the increase in welfare can be traced to these other economic variables. Recall that the three pathways by which energy taxes can lead to efficiency changes are productive and consumptive inefficiency, resource rents, and externalities. However externalities have not yet been included: their impact is examined in Specification 16. In addition, Specifications 6 and 7 in Section 4.2 indicate that resource rents have almost no impact on welfare. This means that the welfare increase of the budget proposal is due to the last remaining pathway, decreased productive and consumptive inefficiency. The changes in production efficiency are themselves determined by two factors, the efficiency of the allocation of inputs across industries and the aggregate level of these inputs.[47]

Since the tax neutrality of the proposal is mixed, it is unclear if the allocation of inputs across sectors improves. However the aggregate supplies of capital and labor are moved closer to their optimal levels. The decision to supply labor or capital is a choice between labor income and leisure or between future and current consumption. Taxes on labor or capital income distort this choice and cause substitution towards the untaxed good (i.e. leisure and current consumption), reducing the supply of labor or capital. By increasing the quantity of labor and capital supplied by households, the proposal increases economic efficiency.

Industry level effects of the budget proposal are similar to the macroeconomic effects. Table 9 presents the effects of the budget proposal on the output price in each industry, the quantity of output the industry produces, and the capital and labor employed by the industry. In general, all these variables increase. As should be expected, since the proposal increases capital

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[47]I refer only to productive efficiency and inputs here because the arguments are exactly the same for consumptive efficiency and goods.

taxes on fossil fuel producing sectors, the capital stock in these sectors falls. The capital stock in petroleum and coal products manufacturing falls the most, by 7.03 percent. However, a number of interesting trends also appear in certain industries. Specifically, output increases for oil and gas extraction, and for petroleum and coal products manufacturing. Only pipeline transportation sees a decline in output.

Table 9: Industry Level Effects of Proposal

| | Percent Change in | | | |
| | Consumer | | Capital | |
Industry	Prices	Output	Stock	Employment
Accommodation and food services	1.26	0.93	0.99	0.75
Administrative and support and waste management and remediation Services	1.26	0.33	0.10	0.10
Agriculture, forestry, fishing, and hunting	0.90	0.15	0.16	-0.05
Arts, entertainment, and recreation	1.25	0.87	1.03	0.71
Construction	1.14	0.00	0.12	-0.43
Educational services	1.25	0.98	1.04	0.84
Finance and insurance	1.02	0.76	0.90	0.44
Health care and social assistance	1.26	0.89	1.05	0.81
Information	1.14	0.51	0.65	0.21
Management of companies and enterprises	0.94	-0.45	-0.37	-0.74
Manufacturing	0.74	0.19	0.27	-0.24
Mining	1.06	0.28	0.16	-0.04
Oil and gas extraction	0.00	1.77	-0.37	3.40
Other services	1.25	0.60	0.57	0.46
Petroleum and coal products manufacturing	1.00	0.22	-7.03	-10.84
Pipeline transportation	1.44	-0.17	-0.73	-0.91
Professional, scientific, and technical services	1.18	0.32	0.48	0.25
Real estate and rental and leasing	1.20	0.48	0.53	0.29
Retail trade	1.20	0.62	0.91	0.21
Transportation and warehousing	1.11	0.03	0.02	-0.44
Utilities	0.95	0.70	0.64	0.13
Wholesale trade	1.18	0.05	0.25	-0.36

The increase in production of fossil fuels is surprising because these are the sectors for which the budget proposal is raising tax rates. The reason for the output increase can be explained by separating the change in output into an negative partial equilibrium effect and a positive general equilibrium effect. The negative partial equilibrium effect of the proposal increases the price of capital for fossil fuel production, leading to higher costs and higher output prices and thus lower demand and lower output. However, the industry will respond to the higher price of capital by substituting to other inputs, which mitigates the impact of the tax on the sector. The significant decrease in the capital stock of fossil fuel production indicates that the industry can substitute fairly easily from capital in response to the capital price increase. At the same time, the positive general equilibrium effect causes an increase in demand due to the expansion

of other sectors of the economy because of increased economic efficiency. Note that the output of almost all industries increases (not just fossil fuel production) and the output of the other industries typically increases by larger amounts. Although it may be somewhat surprising that the general equilibrium effect on fossil fuel production is larger than the partial equilibrium effect, this result is easily explained as the partial equilibrium effect is small due to relatively high capital substitutability in fossil fuel production and is thus more likely to be offset by the general equilibrium effect, which is significant.

To summarize, the increase in fossil fuel production highlights the importance of two innovations of my model: modeling industry specific tax changes in a general equilibrium context and flexible substitution. A partial equilibrium model could only note the partial equilibrium effect on fossil fuel production and would thus conclude that the budget proposal would decrease their demand. But the general equilibrium effect of increased demand due to increased economic efficiency leads to a net increase in demand for fossil fuel producing sectors. Additionally, a model without flexible substitution would overstate the impact of the tax on the price and production of fossil fuels. A model without these two components would not be able to determine that fossil fuel production would actually increase due to the budget proposal.

4.2 Sensitivity Tests

I test the robustness of the results presented thus far with a number of alternative model specifications. These alternate specifications change parameters or assumptions from those in the baseline and examine if results are sensitive to those parameters or assumptions. Recall that in the baseline specification, $\theta_{capital} = 0.5$, $\theta_{labor} = 0.2$, $\theta_{resource} = 0.5$, $\theta_r = 4$, and $\theta_{Arm}^{FossilFuelProduction} = 23$. In addition, in the baseline specification the resource is not treated as capital, the capital average effective tax rates (AETRs) calculated in Section 3.5.1 are used for the capital tax rate, and 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 all of these tests.

Table 10 shows that results are similar under different values of the price elasticities of supply of capital, labor, and resources; in particular, there is little change in the welfare measure. The capital stock also consistently increases under the budget proposal except in the specifications where $\theta_{capital} = 0$. Employment, consumption, and output increase by similar percentages across

Table 10: Macroeconomic Effects of Proposal at Different Elasticities

		Percent Change in				
	Parameter Values[1]	Welfare	Capital Stock	Employment	Consumption	Output
1	Baseline	1.04	0.43	0.07	0.90	0.32
2	$\theta_{capital} = 1$	1.02	0.68	0.08	0.88	0.40
3	$\theta_{capital} = 0$	1.42	0.00	0.06	1.22	0.22
4	$\theta_{labor} = 0.3$	1.14	0.45	0.09	0.94	0.34
5	$\theta_{labor} = 0.1$	0.94	0.42	0.03	0.87	0.30
6	$\theta_{resource} = 1$	1.04	0.43	0.07	0.91	0.32
7	$\theta_{resource} = 0$	1.04	0.43	0.06	0.90	0.32
8	$\theta_r = 0.1$	1.08	0.44	0.07	0.94	0.33
9	$\theta_{capital} = 1, \theta_{labor} = 0.3, \theta_{resource} = 1$	1.16	0.74	0.12	0.96	0.44
10	$\theta_{capital} = 0, \theta_{labor} = 0.1, \theta_{resource} = 0$	1.31	0.00	0.03	1.21	0.21
11	$\theta_{Arm}^{FossilFuelProduction} = 4$	0.17	0.09	0.00	0.15	0.07

Notes: (1) Except where noted under parameter values, all specifications use the same parameter values and method as the baseline (Specification 1).

Table 11: Macroeconomic Effects of Proposal under Different Assumptions

		Percent Change in				
	Parameter Values[1]	Welfare	Capital Stock	Employment	Consumption	Output
12	Energy resource treated as capital	1.16	0.48	0.07	1.00	0.35
13	Mackie (2002) capital METR	1.44	0.60	0.09	1.24	0.43
14	Regression: 2 period lags for IV	0.72	0.31	0.04	0.63	0.23
15	Regression: no instruments	0.67	0.28	0.04	0.58	0.20
16	Maximum social cost of carbon	0.41	0.43	0.07	0.90	0.32

Notes: (1) Except where noted under parameter values, all specifications use the same parameter values and method as the baseline (Specification 1).

all specifications. Specifications 9 and 10 change multiple variables at once. In Specification 9, capital, labor, and resource supply are highly responsive to changes in price, but in Specification 10 they are highly unresponsive. As expected, unresponsive capital supply means capital stock does not change in response to the proposal; however in both specifications, welfare still increases under the proposal.

The only factor that alters results significantly is the Armington elasticity of substitution. In Specification 11, reducing the Armington elasticity substitution of imported and domestic products for fossil fuel production to 4 (from 23 in the baseline simulation) eliminates almost the entire welfare gain for the tax proposal, which falls to 0.17 percent from 1.04 percent. This shows that assumptions about imports drive the 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) the budget proposal would have little effect. 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, overestimate the negative effect of energy taxes on fossil fuel production.

In addition to the parameters examined in Table 10, the robustness of the results can also be considered under more fundamental changes to the model. Table 11 considers a number of such changes and finds that the effects of the budget proposal are positive under all of these specifications as well.

A major goal 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, including resource supplies 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 welfare and the capital stock are slightly larger. Including endogenous resource supply thus lowers the positive impact of the proposal, but the effect is small.

Although Section C.4 mentions a number of advantages the AETR has over the marginal effective tax rate (METR) in this scenario, 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 the calculated capital AETRs. However all the effects of the proposal are still large and positive.

Additionally, I consider several alternative specifications of the regression used to parametrize the consumer and firm translog cost functions. In the baseline, iterated three-stage least squares was used to parametrize the cost function. Intuitively, three-stage least squares can be though 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 with only the IV portion of the regression, with only the SUR portion, and then by ordinary least squares. However, it is not possible to perform the regression without the SUR portion. 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.[48]

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 this specification, the proposal has a positive impact on welfare and capital stock, although smaller in magnitude than the baseline specification. In Specification 15, no

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[48]See Section B.2.2 for a list of what these restrictions are and how they are imposed.

instruments are used at all. However, once again, the proposal has a positive impact on welfare and capital stock. Recall that Section 3.4.2 showed evidence that the baseline specification may be using weak instruments. These sensitivity tests show that the results are not driven by the choice of instruments.

The impact of externalities is considered in the Specification 16. The budget proposal will increase demand for fossil fuels more than the baseline tax increase but with a lower excess burden for consumers. The equivalent variation of the proposal divided by its carbon dioxide increases is at least \$350 per metric ton. Therefore in order for the budget proposal to be efficiency reducing, the cost of externalities caused by the production and fossil fuels and their emissions must exceed \$350 per metric ton. The two externalities mentioned in Treasury (2013) were from carbon emissions and energy security. But the highest social cost of carbon estimated by Interagency Working Group on Social Cost of Carbon (2013) is \$221 per metric ton, and higher domestic production would also lead to a positive energy security externality.[49] Thus, the tax proposal would be efficiency enhancing even with a social cost of carbon at the high end of current estimates.

While varying parameter values is an effective method of determining the sensitivity of model predictions to a small set of parameters, this method cannot be used to evaluate the entire translog cost function because of the large number of parameters involved. Instead I use a Monte Carlo simulation to test the robustness of results to the estimated parameters since Monte Carlo methods can handle large numbers of parameters as long as their distribution is known. New parameter values β are drawn from the multivariate distribution

$$\beta \sim \mathcal{N}(\beta^*, \Sigma^*) \tag{2}$$

where β^* are the estimated parameter values and Σ^* is the estimated variance-covariance matrix from the seemingly unrelated regressions portion of the iterated three-stage least squares regression. 98 draws from this distribution are taken for each variable and taken and the resulting parameters of each draw are used to run a new simulation, with all other parameters as shown in the baseline specification. Results of the simulation are presented in Table 12 for estimates of the effect of the proposal on welfare, capital stock, domestic production, the capital rental rate, and the labor wage rate. These results are consistent with those in the baseline

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[49]The social cost of carbon estimated by Interagency Working Group on Social Cost of Carbon (2013) apparently does not include energy security externalities since it is not explicitly listed.

Table 12: Macroeconomic Effects of Proposal in Monte Carlo Simulation

	Percentile of Percent Change in Variable		
Variable	5%	50%	95%
Welfare	0.47	1.07	1.72
Capital Stock	0.21	0.44	0.69
Employment	0.02	0.07	0.11
Consumption	0.41	0.92	1.49
Output	0.16	0.33	0.56
Capital Rental Rate[1]	0.42	0.88	1.38
Labor Wage Rate[1]	0.11	0.33	0.55

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

specification. Even at the 5th percentile, all variables increase under the budget proposal. Taken together, the Monte Carlo simulation and the other sensitivity tests demonstrate that my baseline results are not purely productions 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 with endogenous resource supply and flexible substitution. 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 neutrality of the proposal, the effects of the proposal, and how energy taxes should be modeled.

First, descriptive analysis of the proposal's provisions and effective tax rates show 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 effect of most provisions is unclear. When taxes on production are taken into account, under current law average effective tax rates on fossil fuel production are higher than those on other sectors. Previous studies calculating marginal effective tax rates on capital employed in fossil fuel production have produced contradictory results. I find that the average effective tax rate on capital used in fossil fuel production is 5.3 percentage points higher than the economy-wide rate. However, when taxes on production are included, fossil fuel production tax rates are 1.5 to 8.7 percentage points higher than the economy-wide rate. These results show that although the proposal improves tax neutrality in some areas, it reduces neutrality in others.

Second, the budget proposal will increase economic efficiency while also increasing fossil

fuel production. The proposal increases the aggregate supply of capital and labor compared to a revenue-neutral capital tax increase. Accordingly, the proposal is more efficient and leads to higher welfare. Surprisingly, domestic fossil fuel production will actually increase due to the net impact of partial and general equilibrium effects. Fossil fuel producers can substitute away from capital in response to the increased tax on their capital with relative ease. This substitution mitigates the increase in their costs from the budget proposal and thus limits the negative partial equilibrium effect of higher prices and lower demand. This negative effect is more than offset by the positive general equilibrium increase in demand for the output of all sectors, including fossil fuels, due to the efficiency-enhancing reform. The increase in fossil fuel production is thus a symptom of the increase in economic efficiency.

Third, the innovations combined in the model significantly impact the estimates of economic efficiency and fossil fuel production. The model differs from previous literature by including endogenous energy supply and cost functions with flexible substitution all in a computable general equilibrium model. The baseline specification shows that the budget proposal would increase fossil fuel production and that both flexible substitution and the computable general equilibrium method contribute to this result. This is because a partial equilibrium model would miss the positive general equilibrium effect entirely while a general equilibrium model with inflexible substitution would overstate the negative partial equilibrium effect. Sensitivity tests reinforce the importance of general equilibrium effects by showing that welfare results are also driven by the general equilibrium effects of import substitution and economy-wide price changes. By contrast, factors more accurately modeled by partial equilibrium models such as resource supply have little impact on welfare estimates. The results show the importance of considering general equilibrium effects and suggest that energy tax models should focus more on the ability of consumers and firms to substitute goods in response to the tax change and less on the resource development decision. Such a strategy would capture the most important effects of an energy tax change.

The surprising increase in fossil fuel production shown by the model suggests an avenue for further study. If substitution enables fossil fuel producers to significantly mitigate their increase in costs due to tax increases on their inputs, then estimates of the production impact of these taxes are overstated in models with limited or no substitution. This situation occurs in all fixed coefficient models and any constant elasticity of substitution model where the single elasticity parameter used for all inputs is less than the true elasticity of substitution between

any pair of inputs. This finding has important implications for a number of different types of energy taxes. For example, a model with limited substitution that analyzed the impact of a carbon tax would overstate the reduction in carbon dioxide emissions. Additionally, analysis of severance or excise taxes on the energy sector would underestimate both tax revenue and economic efficiency. Allowing for flexible substitution in a general equilibrium model, as was done in this paper, eliminates this bias and provides a more accurate model of energy taxation.

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Appendices

A   Data

A.1   Jorgenson (2007)

The data used in the regressions and simulations come from several sources. The first is a system of U.S. 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:

$$Ship_y^x = \sum_{z \in y} Ship_z^x \tag{3}$$

where $Ship_z^x$ are the value of shipments of SIC industry z apportioned to NAICS industry x and $Ship_y^x$ 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:

$$u_{xjt}^{NAICS,JORG} = \sum_{y \in JORG} \frac{Ship_y^x u_{yjt}^{JORG,JORG}}{\sum_{x \in NAICS} Ship_y^x} \tag{4}$$

here $u_{xjt}^{NAICS,JORG}$ is the expenditure on Jorgenson (2007) input j by NAICS industry x at time t, $Ship_y^x$ are the value of shipments of Jorgenson (2007) industry y apportioned to NAICS 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:

$$u_{xit} = \sum_{j \in JORG} \frac{Ship_j^i u_{xjt}^{JORG,NAICS}}{\sum_{i \in NAICS} Ship_j^i} \tag{5}$$

where here u_{xit} 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:

$$u_{xt} = \sum_{j \in JORG} \frac{Ship_j^x u_{jt}^{JORG}}{\sum_{i \in NAICS} Ship_j^i} \tag{6}$$

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:

$$p_{it} = \sum_{j \in SIC} \frac{u_{jt}^{SIC} Ship_j^i}{q_{it} \sum_{i \in NAICS} Ship_j^i}. \tag{7}$$

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:

$$p_{21t} = \frac{p_{21t}^{OLD} Revenue_{21t} - p_{211} Revenue_{211t}}{Revenue_{21t} - Revenue_{211t}} \tag{8}$$

$$p_{31t} = \frac{p_{31t}^{OLD} Revenue_{31t} - p_{324} Revenue_{324t}}{Revenue_{31t} - Revenue_{324t}} \tag{9}$$

$$p_{48t} = \frac{p_{48t}^{OLD} Revenue_{48t} - p_{486} Revenue_{486t}}{Revenue_{48t} - Revenue_{486t}} \tag{10}$$

where p_{kt}^{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:

$$p_{it} = \begin{cases} p_{it}^J & \text{if } t \leq 1997 \\ p_{it}^{BEA} \dfrac{p_{i1997}^J}{p_{i1997}^{BEA}} & \text{if } t > 1997 \end{cases} \tag{11}$$

where p_{it} is the price of commodity i at time t used in the regression, p_{it}^J is the price from Jorgenson (2007) and p_{it}^{BEA} 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.[50] 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.[51]

B   Additional Model Information

B.1   Model Variable Definitions

Tables 13 and 14 define the variables used in the model, excluding the elasticity parameters of Table 2. Table 13 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 14 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 or resources versus capital, labor, energy, and materials.

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

[51]Available online at `http://www.eia.gov/cfapps/frs/frstables.cfm?tableNumber=19&startYear=2003&endYear=2009`.

Table 13: Commodity Variable Notation

Symbol	Definition
p_{xit}	Price of input i to industry x at time t
p_{xkt}	Price of capital to industry x at time t
p_{xlt}	Price of labor to industry x at time t
p_{xrt}	Price of resource to industry x at time t
p_{xi}	Price of input i to industry x
p_k	Vector of prices of capital
p_l	Vector of prices of labor
p_r	Vector of prices of resource
p_{dom}	Vector of prices of domestic output
p_{imp}	Vector of prices of imported output
p_{com}	Vector of prices of composite import/domestic commodity
p_c	Prices of the household composite consumption good

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 14: CES Parameters

Symbol	Definition
α_r	Parameter for Equation 32: Domestic output cost function
α_{KLEM}	Parameter for Equation 32: Domestic output cost function
α_{import}	Parameter for Equation 38: Composite output cost function
$\alpha_{domestic}$	Parameter for Equation 38: Composite output cost function

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 cost shares, one for each input, given by

$$share_{xoit} = \sum_{i=1}^{N} \beta_{xij}^{substitution} ln\left(p_{xit}\right) + \beta_{xi}^{share\ trend} t + \beta_{xi}^{share\ constant} \tag{12}$$

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 $\beta_{xi}^{share\,constant} \equiv \beta_{xi}^{sc}$.

$$share_{xo1t} =$$

$$\beta_{x1}^{sc} - (-\beta_{x1}^{sc} + \beta_{x1}^{sc\,2} + e^{2d_{x11}})ln(p_{x1t}) - (\beta_{x1}^{sc}\beta_{x2}^{sc} + e^{d_{x11}+d_{x12}})ln(p_{x2t})$$

$$-(\beta_{x1}^{sc}\beta_{x3}^{sc} + e^{(d_{x11}+d_{x13})})ln(p_{x3t}) + (0 + (-\beta_{x1}^{sc} + \beta_{x1}^{sc\,2} + e^{2d_{x11}})$$

$$+(\beta_{x1}^{sc}\beta_{x2}^{sc} + e^{d_{x11}+d_{x12}}) + (\beta_{x1}^{sc}\beta_{x3}^{sc} + e^{d_{x11}+d_{x13}}))ln(p_{x4t}) + \beta_{x1}^{share\,trend}year + \varepsilon_{xo1t} \qquad (13)$$

$$share_{xo2t} =$$

$$\beta_{x2}^{sc} - (\beta_{x1}^{sc}\beta_{x2}^{sc} + e^{d_{x11}+d_{x12}})ln(p_{x1t}) - (-\beta_{x2}^{sc} + \beta_{x2}^{sc\,2} + e^{2d_{x12}} + e^{2d_{x22}})ln(p_{x2t})$$

$$-(\beta_{x2}^{sc}\beta_{x3}^{sc} + e^{d_{x12}+d_{x13}} + e^{d_{x22}+d_{x23}})ln(p_{x3t}) + (0 + (\beta_{x1}^{sc}\beta_{x2}^{sc} + e^{d_{x11}+d_{x12}})$$

$$+(-\beta_{x2}^{sc} + \beta_{x2}^{sc\,2} + e^{2d_{x12}} + e^{2d_{x22}}) + (\beta_{x2}^{sc}\beta_{x3}^{sc} + e^{d_{x12}+d_{x13}} +$$

$$e^{d_{x22}+d_{x23}}))ln(p_{x4t}) + \beta_{x2}^{share\,trend}year + \varepsilon_{xo2t} \qquad (14)$$

$$share_{xo3t} =$$

$$\beta_{x3}^{sc} - (\beta_{x1}^{sc}\beta_{x3}^{sc} + e^{d_{x11}+d_{x13}})ln(p_{x1t}) - (\beta_{x2}^{sc}\beta_{x3}^{sc} + e^{d_{x12}+d_{x13}} + e^{d_{x22}+d_{x23}})ln(p_{x2t})$$

$$-(-\beta_{x3}^{sc} + \beta_{x3}^{sc\,2} + e^{2d_{x13}} + e^{2d_{x23}} + e^{2d_{x33}})ln(p_{x3t}) + (0 + (\beta_{x1}^{sc}\beta_{x3}^{sc} + e^{d_{x11}+d_{x13}})$$

$$+(\beta_{x2}^{sc}\beta_{x3}^{sc} + e^{d_{x12}+d_{x13}} + e^{d_{x22}+d_{x23}}) + (-\beta_{x3}^{sc} + \beta_{x3}^{sc\,2} + e^{2d_{x13}} +$$

$$e^{2d_{x23}} + e^{2d_{x33}}))ln(p_{x4t}) + \beta_{x3}^{share\,trend}year + \varepsilon_{xo3t} \qquad (15)$$

where ε_{xojt} 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:

$$\beta_{x11}^{substitution} = -(\beta_{x1}^{sc\,2} + e^{2d_{x11}}) + \beta_{x1}^{sc} \tag{16}$$

$$\beta_{x12}^{substitution} = -(\beta_{x1}^{sc}\beta_{x2}^{sc} + e^{d_{x11}+d_{x12}}) \tag{17}$$

$$\beta_{x13}^{substitution} = -(\beta_{x1}^{sc}\beta_{x3}^{sc} + e^{d_{x11}+d_{x13}}) \tag{18}$$

$$\beta_{x14}^{substitution} = 0 - \beta_{x11}^{substitution} - \beta_{x12}^{substitution} - \beta_{x13}^{substitution} \tag{19}$$

$$\beta_{x22}^{substitution} = -(\beta_{x2}^{sc\,2} + e^{2d_{x12}} + e^{2d_{x22}}) + \beta_{x2}^{sc} \tag{20}$$

$$\beta_{x23}^{substitution} = -(\beta_{x2}^{sc}\beta_{x3}^{sc} + e^{d_{x12}+d_{x13}} + e^{d_{x22}+d_{x23}}) \tag{21}$$

$$\beta_{x24}^{substitution} = 0 - \beta_{x12}^{substitution} - \beta_{x22}^{substitution} - \beta_{x23}^{substitution} \tag{22}$$

$$\beta_{x33}^{substitution} = -(\beta_{x3}^{sc\,2} + e^{2d_{x13}} + e^{2d_{x23}} + e^{2d_{x33}}) + \beta_{x3}^{sc} \tag{23}$$

$$\beta_{x34}^{substitution} = 0 - \beta_{x23}^{substitution} - \beta_{x33}^{substitution} - \beta_{x13}^{substitution} \tag{24}$$

$$\beta_{x4}^{sc} = 1 - \beta_{x1}^{sc} - \beta_{x2}^{sc} - \beta_{x3}^{sc} \tag{25}$$

$$\beta_{x44}^{substitution} = 0 - \beta_{x14}^{substitution} - \beta_{x24}^{substitution} - \beta_{x34}^{substitution} \tag{26}$$

$$\beta_{x4}^{share\,trend} = 0 - \beta_{x1}^{share\,trend} - \beta_{x2}^{share\,trend} - \beta_{x3}^{share\,trend}. \tag{27}$$

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

$$c_{x,KLEM,t} = p_{x,dom,t}. \tag{28}$$

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. 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. 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:

$$\sum_i \beta_{xi}^{shareconstant} = 1 \qquad\qquad \forall x \qquad\qquad (29)$$

$$\sum_i \beta_{xi}^{sharetrend} = 0 \qquad\qquad \forall x \qquad\qquad (30)$$

$$\beta_{xij}^{substitution} = \beta_{xji}^{substitution} \qquad\qquad \forall x, i, j \qquad\qquad (31)$$

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 and 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 15 presents results of this calculation.[52] 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 share of the other commodities to alter results 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 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 λ 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 15 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 15's results are what is obtained after all efforts to improve the function's concavity.

B.3   Other Cost Functions

The translog cost function describes how good KLEM is produced. However, this good cannot be directly used to satisfy demand. 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.

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: $q_{x,resource} = 0$ and $p_{x,dom} = p_{x,KLEM}$ if $x \neq$ oil and gas extraction.

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[52]These are the mean values of the summary statistics averaged over all industries. See the Online Appendix at `http://barbe.blogs.rice.edu/files/2013/11/Online-Appendix-1.pdf` for full results.

Table 15: Regression Statistics: Nonnegativity and Monotonicity

Commodity	Nonnegative (%)	Monotonic (%)
11	100	na
21	100	na
211	99	na
22	100	na
23	99.7	na
31	100	na
324	99.9	na
42	100	na
44	100	na
48	100	na
486	99.9	na
51	100	na
52	100	na
53	100	na
54	100	na
55	100	na
56	100	na
61	100	na
62	100	na
71	100	na
72	100	na
81	100	na
E	100	20.6
K	100	na
L	100	na
M	100	36.2
MM	100	69.7
MO	100	48.9
MOT	100	65.6
MP	100	83.4
MS	100	89.6
MSS	100	82.6
N	100	na
KLEM	na	68.2

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.

Figure 3: Tiers and Cost Functions to Create Composite Output
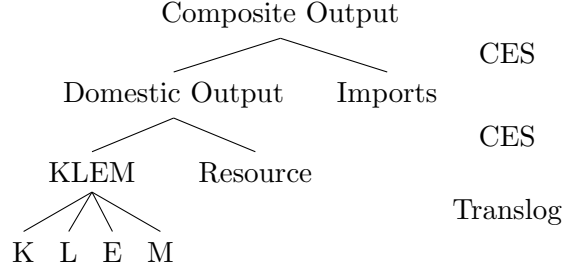
Notes: See Section 3.4.1 for the tier structure of producing KLEM.

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

$$c_{dom}(p_{KLEM}, p_r) = \frac{1}{\phi_{dom}}(\alpha_r^{\theta_r} p_r^{1-\theta_r} + \alpha_{KLEM}^{\theta_r} p_{KLEM}^{1-\theta_r})^{\frac{1}{1-\theta_r}} \tag{32}$$

with

$$\alpha_{KLEM} = 1 - \alpha_r \tag{33}$$

and

$$\phi_{dom} = (\alpha_r^{\theta_r} p_{r2005}^{1-\theta_r} + \alpha_{KLEM}^{\theta_r} p_{KLEM,2005}^{1-\theta_r})^{\frac{1}{1-\theta_r}} / p_{dom,2005}. \tag{34}$$

The cost share of the resource is

$$\frac{u_r}{u_r + u_{KLEM}} = \frac{\alpha_r^{\theta_r} p_r^{1-\theta_r}}{\alpha_r^{\theta_r} p_r^{1-\theta_r} + \alpha_{KLEM}^{\theta_r} p_{KLEM}^{1-\theta_r}} \tag{35}$$

and the value of α_{KLEM} is calibrated for the year 2005 by solving for the α_{KLEM} that gives the 2005 cost share of the resource:

$$\frac{u_{r,2005}}{u_{r,2005} + u_{KLEM,2005}} = \frac{\alpha_r^{\theta_r} p_{r,2005}^{1-\theta_r}}{\alpha_r^{\theta_r} p_{r,2005}^{1-\theta_r} + \alpha_{KLEM}^{\theta_r} p_{KLEM,2005}^{1-\theta_r}}. \tag{36}$$

The assumption of perfectly competitive markets means that p_{KLEM} is equal to the cost

times one plus the production tax rate

$$p_{dom} = c_{dom}(1 + \tau_{production}).$$ (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_{dom} and imports p_{import}.

$$p_{com} = c_{com}(p_{dom}, p_{import}) = \frac{1}{\phi_{com}}(\alpha_{dom}^{\theta_{Arm}} p_{dom}^{1-\theta_{Arm}} + \alpha_{import}^{\theta_{Arm}} p_{import}^{1-\theta_{Arm}})^{1/(1-\theta_{Arm})}$$ (38)

where

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

This value of ϕ was chosen so that if input prices are equal, they equal composite price

$$c_{com}(x, x) = x$$ (40)

Its total quantity is equal to the sum of the supplies of the domestic and imported good

$$q_{com} = q_{dom} + q_{imports}.$$ (41)

Solving for α_{import} in terms of the other variables gives

$$\alpha_{import} = \left(\frac{u_{import}}{u_{domestic} + u_{import}} \left(\frac{p_{dom}}{p_{import}} \right)^{1-\theta_{Arm}} \right)^{\frac{1}{\theta_{Arm}}}$$ (42)

and

$$\alpha_{import} = 1 - \alpha_{dom}.$$ (43)

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 α_{import}, it is partially calibrated as

$$\alpha_{import} = \left(\frac{u_{import,2005}}{u_{dom,2005} + u_{import,2005}} \left(\frac{p^*_{dom}}{p_{import}} \right)^{1-\theta_{Arm}} \right)^{\frac{1}{\theta_{Arm}}} \tag{44}$$

where p^*_{dom} is the value of p_{dom} for a simulation using the model baseline specification's elasticity parameter values but without the budget proposal or the alternative tax implemented. p^*_{dom} is used instead of $p_{dom,2005}$ which would calibrate α_{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. This is critically important for import substitution because of the extremely high Armington elasticities involved, especially for the critically important fossil fuel production sectors. Calibrating α_{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.

B.4 Removing Resource From Capital Stock

Since the other data includes these resource acquisition expenditures as part of capital expenditures, they are subtracted as follows:

$$q_{jkt,BASELINE} = q_{jk2005} - \frac{u_{r,2005}}{p_{jk2005}}. \tag{45}$$

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

$$\beta_{xi}^{shareconstant} = \beta_{xi}^{shareconstant,OLD} + \frac{u_{x,i,BASELINE}}{u_{x,o,BASELINE}} - \frac{u_{x,i,2005}}{u_{x,o,2005}}. \tag{46}$$

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:

$$p_{KLEM} = p_{dom} \prod_{i \in k,l,e,m} (p_{xi2005})^{\frac{u_{x,i,BASELINE}}{u_{x,o,BASELINE}} - \frac{u_{x,i,2005}}{u_{x,o,2005}}}. \tag{47}$$

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 is defined 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:

$$\sum_x q_{xk} = \sum_x q_{x,k,BASELINE} \left(\frac{(1-\tau_k)p_k/p_c}{(1-\tau_{k,2005})p_{k,2005}/p_{c,2005}} \right)^{\theta_{capital}}. \tag{48}$$

Capital is assumed to be perfectly mobile across industries such that for any two industries x and y:

$$(1-\tau_{xk})p_{xk} = (1-\tau_{yk})p_{yk}. \tag{49}$$

B.5.2 Labor

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

$$\sum_x q_{xl} = \sum_x q_{x,l,2005} \left(\frac{(1-\tau_l)p_l/p_c}{(1-\tau_{l,2005})p_{l,2005}/p_{c,2005}} \right)^{\theta_{labor}}. \tag{50}$$

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:

$$(1-\tau_l)p_l = \alpha(1-\tau_{l,2005})p_{l,2005} \tag{51}$$

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

B.5.3 Resource

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

$$u_{r,2005} = \sum_{t=2003}^{2005} AQC_t^{FRS} \frac{\sum_{t=2003}^{2005} R_t^{All}}{3 \sum_{t=2003}^{2005} R_t^{FRS}} \tag{52}$$

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.[53] 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 Consumer Price Index.

From this, total resource supply is defined as

$$q_r = q_{r,2005} \left(\frac{(1-\tau_r)p_r/p_c}{(1-\tau_{r,2005})p_{r,2005}/p_{c,2005}} \right)^{\theta_{resource}}. \tag{53}$$

B.6 Demand Functions

Demand for the composite commodity comes from 5 sources: exports, imports, government demand, household consumption demand, and household investment demand.

$$q_{final} = q_{export} + q_{government} + q_{consumption} + q_{investment} \tag{54}$$

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

$$q_{final} = q_{com}. \tag{55}$$

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

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[53]1 billion cubic feet feet of natural gas equals .178 million barrels of oil equivalents (U.S. Energy Information Administration, 2011).

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:

$$q_{government} = q_{government,2005} \frac{p_{com}}{p_{com,2005}}. \tag{56}$$

B.6.4 Household Investment Demand

Household investment demand of composite commodity is equal to:

$$q_{investment} = \frac{\sum_x q_{x,k}}{\sum_x q_{x,k,2005}} \frac{p_{com}}{p_{com,2005}} S_{inv,2005} \tag{57}$$

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.

This leads a notable disadvantage of my methodology shared all models that calibrate investment spending off empirical values. 2005, or any particular year, is not a steady state equilibrium where investment exactly equals depreciation. In fact, in 2005, investment exceeds capital factor payments, implying that capital factor payments in an actual steady state equilibrium would be higher than they are in 2005. This would bias simulation results. However, since the simulation shows that the budget proposal has higher capital stock than the alternative, the bias understates the benefits of the proposal. Since I find that the proposal has positive benefits, a perfect model would also find the same sign on the result, just larger in magnitude.

B.6.5 Export Demand

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

$$q_{export} = q_{export,2005} \left(\frac{p_{com}}{p_{com,2005}} \right)^{\theta_{export}}. \tag{58}$$

B.6.6 Household Income and Spending

Households own all factors of production and receive income from their use. Income is calculated in two steps. First post-tax income is calculated from the supply of capital, labor, and resources

$$I_j = \sum_x q_{xk} p_{xk}(1 - \tau_{xk}) + q_{xl} p_{xl}(1 - \tau_{xl}) + q_{xr} p_{xr}(1 - \tau_{xr}) \tag{59}$$

where x indexes industry. Then this value is multiplied by a factor calibrated to give the actual sum of 2005 private consumption and investment spending on all sources:

$$I = \frac{I_j}{I_j, 2005} I_{BEA,actual} \tag{60}$$

where $HHIncome_{BEA,actual}$ is the sum of private consumption and investment spending in 2005. This is necessary because the Jorgenson (2007) are normalized to 1 in the year 1996. This means that the product of prices and quantities (from which income is calculated) in this data set do not sum to the same value as before normalization.

Household spending is given by:

$$S = \sum_x p_{com,x}(q_{consumption,x} + q_{investment,x}) \tag{61}$$

and the budget condition requires spending to equal income:

$$S = I. \tag{62}$$

B.7 Household Utility

A representative household maximizes utility by allocating time between labor and leisure. Expressed in terms of of the composite consumption good c, labor supply l, per ton carbon externalities b, and total carbon emissions C, household utility is

$$U(q_c, q_l, b) = q_c - L_0 q_l^{1+1/\theta_{labor}} + f(bC) \tag{63}$$

where

$$L_0 = q_{l,2005}^{-1/\theta_{labor}} \frac{\theta_{labor}}{\theta_{labor} + 1} \frac{(1 - \tau_{l,2005})p_{l,2005}}{p_{c,2005}}. \tag{64}$$

The utility function is additively separable between leisure, consumption, and the externalities. It is linear in leisure and the form of the labor term is chosen in order to generate the isoelastic labor supply of Equation 50.

B.7.1 Externalities

The percent change in household welfare due to the proposal when fossil fuel production and consumption externalities are nonzero is

$$\Delta U(q_c, q_l, b) = \Delta U(q_c, q_l, 0) \frac{W T_{JCT} - T_{model} b \Delta C}{W T_{JCT}} \tag{65}$$

where variables are defined as follows: ΔC is the change in carbon emissions in metric tons. W is equal to the equivalent variation of the proposal compared to the uniform tax increase. However, since this value is in model notation and not in real dollars, it is not directly comparable to social cost of carbon estimates from the literature. T_{JCT}, the JCT (2013) revenue estimate of the entire budget proposal, and T_{model} the revenue generated by the proposal in the model, are used to convert model notation into real dollars which are comparable. b is the per ton social cost of carbon. Because externalities are separable from the other components of the utility function, $f(bC)$ does not have to be specified in order to derive Equation 65.

The change in carbon emissions is

$$\Delta C = \Delta q_{max} C \tag{66}$$

where Δq_{max} is equal to the largest percent increase in output by an energy sector (1.00 percent for petroleum and coal products manufacturing) 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`. This definition of ΔC gives an upper bound on the actual increase in carbon emissions for the entire economy from the proposal and thus also an upper bound on the impact of carbon externalities.

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

$$T_{capital} = \sum_x q_{xk} p_{xk} \tau_{capital,x} \tag{67}$$

$$T_{labor} = \sum_x q_{xl} p_{xl} \tau_{labor,x} \tag{68}$$

$$T_{resource} = q_r p_r \tau_{resources} \tag{69}$$

$$T_{production} = \sum_x q_{dom,x} p_{dom,x} \frac{\tau_{production,x}}{1 + \tau_{production,x}} \tag{70}$$

$$T_{total} = T_{capital} + T_{labor} + T_{resource} + T_{production}. \tag{71}$$

C Current Law Tax Rates

C.1 Overview

It is important to frame the discussion of the individual tax changes proposed by the president in the context of the existing taxes and subsidies faced by fossil fuel producers. 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). Treasury (2013) also stated that tax preferences encourage more investment in fossil fuel production than would occur under a neutral tax system. There has been significant research in recent years on the tax rates faced by the energy sector, and Congressional Budget Office (2005b), hereafter CBO, found that the income from investment in energy capital faced a lower tax rate than the income from other types of capital investment.

In this section, I take a broad look at the taxes and tax rates facing consumers, producers, capital, and labor involved with fossil fuel production and compare them to those faced by the economy as a whole. Part of this examination lets me examine the issue raised by the administration, tax rates faced by fossil fuel producing capital. But I also look more broadly

at other taxes and agents.

This is done by first looking at different types of taxes on the sector. In addition to the capital taxes that have been the focus of the literature, production taxes such as severance or excise taxes are also imposed on the extraction and refining of fossil fuels. These taxes are a large source of government revenue but have received little attention compared to capital taxes. 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 other sectors.

However, there are multiple methods to measure effective tax rates. Upon reviewing the effective tax rate measures that have been proposed 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. As I have said before, I am not interested only in the taxes borne by capital owners but also that by factors of production such as labor or consumers of fossil fuels. To this end, I report results not just for capital taxes but also all taxes, both under the assumption that they are borne by consumers and under the assumption that they are borne by the factors of production.

C.2 Capital Taxes

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

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[54]The average effective tax rate is also known simply as the average tax rate.

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 variance 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 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.[56] However, note that these results are for particular assets used only by energy industries, not the industry as a whole.

Mackie (2002) calculates METRs for assets but also aggregates them over industries. 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

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[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 distributions from non-qualified annuities. See CBO (2005) Table A-4 for more details.

[56]C corporations are corporations that are taxed separately from their owners. The corporate income tax applies solely to C corporations.

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.

C.3   Other Taxes

In addition to capital taxes, fossil fuel production faces a large number of other taxes such as sales, property, severance, and excise taxes. As seen in Table 16, total payments for these taxes, less subsidies, by fossil fuel producing sectors exceed payments for corporate income taxes.[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. In the next section, I attempt to do so for the combined effect of capital and other taxes by calculating average effective tax rates (AETR).

Table 16: Total Tax Payments by Industry, 1998-2009 ($ million, 2008)

Sector	Corporate Income Taxes	Other Production Taxes
Oil and gas extraction	42,715	227,965
Petroleum and coal products manufacturing	213,416	29,153
Pipeline transportation	4,249	20,723
Fossil fuel production[1]	260,381	277,842
All sectors	4,107,379	11,075,086

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.4   Average Effective Tax Rates

C.4.1   Average Effective Tax Rate Estimates

Tax burden is estimated using the average effective tax rates (AETR) as opposed to marginal effective tax rates (METR). 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

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[57]Both corporate income tax statistics and the other production tax statistics include all such taxes at the federal, state, and local levels.

depreciation (Collins and Shackelford, 1995).[58] In addition, the calculation must explicitly choose which provisions of the tax code (which deductions, which tax credits) to include and how to model them. As a practical matter, they must pick and choose what provisions to include and this will lead the calculation 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).[59]

In this analysis, I calculate tax rates using the AETR method because the information required to credibly calculate METRs for use in a general equilibrium model simply does not exist for two critical areas: the types of capital whose tax treatment are changing in the budget, and production taxes 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 taxes 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 the next section and 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, also by the BEA.[60] I use table 3.4ES: Current-Cost Depreciation of Private Fixed Assets by Industry and table

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[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 AETR.

[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.

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.

Due to data limitations, this measure includes firm level taxes but does not include individual level capital income taxation such as that 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 such that total capital taxes for the entire economy 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 affect the conclusion that fossil fuel production is taxed at a higher AETR than other sectors, their impact on capital tax rates would also need to vary systematically by industry, but with larger size and negative correlation to the rates calculated in this section.[61]

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.[62] 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. 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.

C.4.2 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

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[61]Since I cannot disprove this possibility, additional results are presented in Section 4 using METRs instead of AETRs

[62]Taxes on production and imports, subsidies, net operating surplus, and compensation of employees are defined in `http://www.bea.gov/national/pdf/chapters1-4.pdf` pages 2-8 to 2-9. Corporate income tax is defined in `http://www.bea.gov/scb/pdf/naTIOnaL/NIPA/Methpap/methpap2.pdf` on page 3.

Table 17: Average Effect Tax Rates by Industry for 1998-2009 (Percent)

Industry	Capital	Value of Output	Factor Income
Management of companies and enterprises	138.7	12.7	22.5
Petroleum and coal products manufacturing	21.1	5.2	22.2
Finance and insurance	20.2	6.6	14.2
Retail trade	15.8	17.4	26.2
Manufacturing	14.8	2.9	9.9
Fossil fuel production	12.8	7.4	28.5
Mining	9.5	5.8	15.6
Wholesale trade	9.2	17.5	26.0
Utilities	8.9	14.4	34.0
Information	8.4	6.0	14.4
All industries	7.5	5.9	12.3
Educational services	7.2	3.4	6.0
Pipeline transportation	6.1	7.5	29.1
Transportation and warehousing	5.4	3.6	8.2
Oil and gas extraction	4.5	12.1	38.2
Accommodation and food services	4.1	7.1	13.7
Construction	3.2	1.0	2.2
Administrative and waste management services	3.1	1.8	3.0
Health care and social assistance	3.0	1.7	3.1
Professional, scientific, and technical services	1.7	2.1	3.3
Arts, entertainment, and recreation	1.6	7.8	13.8
Other services, except government	0.8	3.4	5.8
Agriculture, forestry, fishing, and hunting	0.7	-2.6	-8.5
Real estate and rental and leasing	0.3	8.1	14.0

than the median yearly rate. Tables 17 and 18 investigate this possibility by breaking results down by industry and year.

The most notable outliers in Table 17 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 18 indicates that results are not driven by any particular year. AETR are higher for fossil fuel production than the all industry average on all measures and years with only one exception: capital in 1998.

Table 18: Average Effective Tax Rates by for Select Industries for 1998-2009 (Percent)

Year	Fossil Fuel Production			All Industries		
	Capital	Value of Output	Factor Income	Capital	Value of Output	Factor Income
2009	5.8	6.3	26.7	5.4	5.8	11.7
2008	11.3	6.7	27.6	6.2	5.6	12.0
2007	15.1	7.9	31.0	9.0	6.2	13.2
2006	17.4	8.6	31.9	10.0	6.5	13.7
2005	17.4	8.9	29.6	9.3	6.3	13.2
2004	15.2	8.8	27.0	7.4	6.0	12.4
2003	9.8	7.1	23.4	6.5	5.8	11.8
2002	6.0	5.6	26.5	5.4	5.5	11.3
2001	10.7	7.0	25.0	5.9	5.3	11.0
2000	17.5	7.1	33.1	8.1	5.7	12.0
1999	10.2	6.0	32.5	8.2	5.9	12.3
1998	7.7	6.7	26.8	8.4	6.0	12.5