OCS Study
BOEM 2021-072

Consumer Surplus and Energy Substitutes for OCS Oil and Gas Production: The 2021 Revised Market Simulation Model (MarketSim)

Model Description

US Department of the Interior
Bureau of Ocean Energy Management
Headquarters
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by

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DISCLAIMER

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Abbreviations and Acronyms

AEO	Annual Energy Outlook
API	American Petroleum Institute
BOEM	Bureau of Ocean Energy Management
DOE	Department of Energy
E&D	Exploration and Development
EIA	Energy Information Administration
EMF	Energy Modeling Forum
IEA	International Energy Agency
LNG	Liquefied Natural Gas
MarketSim	Market Simulation Model
NETL	National Energy Technology Laboratory
NEMS	National Energy Modeling System
OCS	Outer Continental Shelf
OECM	Offshore Environmental Cost Model
UNLV	University of Nevada, Las Vegas

1. Background

The Bureau of Ocean Energy Management (BOEM) is charged with assisting the U.S. Secretary of the Interior in carrying out the mandates of the Outer Continental Shelf (OCS) Lands Act, which calls for expedited exploration and development of the OCS to, among other goals, "reduce dependence on foreign sources and maintain a favorable balance of payments in world trade." The OCS Lands Act also requires that BOEM prepare forward-looking five-year schedules of proposed OCS lease sales that define as specifically as possible the size, timing, and location of the OCS area(s) to be offered for lease.

As part of the development of these "Five-Year Programs," BOEM completes an analysis of the energy market's response to production anticipated to emerge from leases issued under these programs. This document comprises a detailed description of the methodology used by BOEM to measure the energy market response to new production on leases issued in different planning areas under a specific program. The analytical tool which BOEM employs internally to estimate this market response is called the Market Simulation Model (MarketSim). As might be expected, key inputs to the model are the anticipated amounts of new annual OCS oil and gas production. The magnitudes of these production estimates are based on assessments of the non-leased, economically recoverable oil and gas resources in each planning area, and on historical trends in leasing and production.

The timing of these production estimates emerges from stipulated Exploration and Development (E&D) scenarios in each planning area. An E&D scenario defines the incremental level of OCS exploration, development and production activity anticipated to occur within planning areas expected to be made available for leasing in the BOEM Five-Year OCS Oil and Gas Leasing Program. Elements of an E&D scenario include the number of exploration wells drilled, the number of platforms installed, the number of development wells drilled, miles of new pipeline constructed, anticipated aggregate oil and gas production, and the number of platforms removed. A crucial output of the model calculations based on the E&D scenario production is the net change in consumer surplus, which is an important part of the measure of net social benefits from adoption of the Five-Year Program.

A companion document (*Forecasting Environmental and Social Externalities Associated with OCS Oil and Gas Development*) describes the calculations and supporting data for another model BOEM uses to estimate the net environmental and social costs attributable to the program proposal, net of the environmental and social costs attributable to the No Action Alternative, that is, from energy sources that would substitute for OCS production in the absence of the Five-Year Program (Industrial Economics 2018). The outputs of this model's calculations represent another important part of the measure of net social benefits from adoption of the Five-Year Program.

2. Model Description

What follows is the general framework for MarketSim's economics-based model representation of U.S. energy markets. The model simulates end-use domestic consumption of oil, natural gas, coal and electricity in four sectors (residential, commercial, industrial and transportation); primary energy production; and the transformation of primary energy into electricity. The model mostly represents U.S. energy markets, but it also captures interaction with world energy markets as appropriate. As in the previous version, the current MarketSim takes current measures of energy production, consumption, and prices assuming no new OCS leasing as a baseline to which a given scenario of OCS production is added. Accounting for substitution between different sources of energy, the model calculates equilibrating prices for oil, natural gas, coal, and electricity based upon the user-specified increase in OCS production of oil and gas.

As a point of departure for scenario analyses, MarketSim is calibrated to reproduce a specified baseline projection, such as the reference case in the Energy Information Administration's (EIA) *Annual Energy Outlook (AEO)* or other output produced by the EIA's National Energy Modeling System (NEMS), for the baseline projection. The user-specified offshore production scenario then is added to the production side of the market equilibration, and the model adjusts prices until all markets converge on a new equilibrium.

3. Baseline Supply and Demand Projections

The baseline supply and demand projections in MarketSim were obtained from a customized model run of EIA's NEMS model.[1] The standard NEMS runs conducted for EIA's *AEO* series assume the issuance of new leases for OCS oil and natural gas production. Given that the purpose of MarketSim is to assess the market impacts of new leases relative to a scenario without new leasing, these new leases should not be included in the MarketSim baseline. Thus, the customized NEMS runs developed for use in MarketSim deviated from the reference case in the *AEO* by removing new offshore leasing on the OCS off the lower 48 states from the model's calculations.[2] The results of this NEMS run constitute the baseline data incorporated into the model.

4. Model Framework

MarketSim's approach to developing an energy model for policy evaluation is to represent the observed conditions prevailing at any moment in the market as observable short-run conditions that are the result of a market equilibrating process and the partial adjustment toward long-run demand and supply conditions. These long-run conditions are not directly observable, but can be inferred from observed market conditions and the underlying parameters of the model. The result is a model that is characterized by partial adjustment toward a long-run equilibrium in each time period.

To create such a model, it is necessary to provide a set of assumed long-run elasticities and partial adjustment parameters. These are developed by reviewing the appropriate economic research, using technology assessments and by making comparisons across existing runs of NEMS to infer elasticities (see below). The supply and demand equations in the sections that follow show how MarketSim applies these partial adjustment parameters and long-run supply and demand elasticities.

5. Oil Market

MarketSim represents the world oil market with sector detail for the United States, a single supply equation for non-U.S. production, and a small number of demand equations for non-U.S. consumption. Oil use for electricity generation is represented in the section on electricity below. The equations that follow specify MarketSim's estimation of U.S. oil demand, non-U.S. oil demand, U.S. oil supply, non-

[1] The MarketSim model extrapolates the baseline data provided in the NEMS projection forecasts to cover the life of leases issued in the Five-Year Program.

[2] See supporting documentation accompanying the delivery of prior NEMS output (Gruenspecht 2009). The data incorporated into the current version of MarketSim are consistent with the "Constrained Supply" scenario described in this document.

U.S. oil supply, oil imports delivered to the U.S. by tanker, U.S. crude oil exports, and U.S. exports of refined petroleum products.

5.1 U.S. Oil Demand

$$Q_{Doi,t} = A_{oi,t} \cdot P_{o,t}^{\eta_{oi}} \cdot \prod_j P_{j,t}^{\eta_{oji}} + (1-\gamma_{Doi})Q_{Doi,t-1}$$

for each U.S. end-use sector *i*; and *j* = *g* (gas), *c* (coal), and *e* (electricity) where:

> $Q_{Doi,t}$ represents the quantity of oil demanded in sector *i* at time *t*,
> $A_{oi,t}$ is a constant calibrated to baseline data,
> $P_{o,t}$ is the price of oil at time *t*,
> η_{oi} is the long-run price elasticity of oil demand in sector *i*,
> $P_{j,t}$ is the price of energy source *j* at time *t*,
> η_{oji} is the long-run elasticity of demand for oil with respect to the price of energy source j in sector i, and
> γ_{Doi} is the rate at which demand for oil in sector *i* adjusts.[3]

The four U.S. end-use sectors *i* are residential, commercial, industrial, and transportation.

5.2 Non-U.S. Oil Demand

$$Q_{Dox,t} = A_{ox,t} \cdot P_{o,t}^{\eta_{ox}} + (1-\gamma_{Dox})Q_{Dox,t-1}$$

where

> $Q_{Dox,t}$ represents the quantity of non-U.S. oil demand at time *t*,
> $A_{ox,t}$ is a constant calibrated to baseline data,
> η_{ox} is the long-run price elasticity of non-U.S. oil demand, and
> γ_{Dox} is the rate at which non-U.S. oil demand adjusts.

Non-U.S. oil demand is strictly a function of the oil price, and no other prices, domestic or foreign. MarketSim specifies three categories of non-U.S. oil demand: (1) non-U.S. demand for U.S. crude oil, (2) non-U.S. demand for U.S. refined products, and (3) non-U.S. demand for non-U.S. oil. The model assumes that these three categories are mutually exclusive.

5.3 U.S. Oil Supply

$$Q_{Sou,t} = B_{ou,t} \cdot P_{o,t}^{\eta_{ou}} + (1-\gamma_{Sou})Q_{Sou,t-1}$$

for each domestic source *u* = lower 48 onshore (conventional), lower 48 onshore (tight), lower 48 offshore, Alaska onshore, Alaska offshore, biofuels, other, rest of world; where

> $Q_{Sou,t}$ represents the quantity of oil supplied from U.S. source *u* at time *t*,
> $B_{ou,t}$ is a constant calibrated to baseline data,

[3] Note that this deviates from standard notation used in the empirical literature on demand and supply estimation by using gammas to represent adjustment rather than persistence.

η_{ou} is the long-run elasticity of oil supply from source *u*, and
γ_{Sou} is the rate at which U.S. oil supply *u* adjusts.

Consistent with the EIA classification, the term "oil" includes all liquid fuels that are close substitutes for petroleum products (e.g., biofuels).

5.4 Non-U.S. Oil Supply

$$Q_{Soy,t} = B_{oy,t} \cdot P_{o,t}^{\eta_{oy}} + (1-\gamma_{Soy})Q_{Soy,t-1}$$

where

$Q_{Soy,t}$ represents the quantity of non-U.S. oil supplied at time *t*,
$B_{oy,t}$ is a constant calibrated to baseline data,
η_{oy} is the long-run elasticity of non-U.S. oil supply, and
γ_{Soy} is the rate at which non-U.S. oil supply adjusts.

Non-U.S. oil supply is estimated in MarketSim's equilibrating equations as a separate value that represents tanker imports and pipeline imports combined, consistent with *AEO* reporting.

5.5 Oil Imports Delivered via Tanker

MarketSim uses the equations outlined above to find changes in oil market consumption, production, and prices under a given E&D scenario. These equilibrating equations do not distinguish between pipeline and tanker imports of oil. To assess the environmental impacts of the No Action Alternative, however, the Offshore Environmental Cost Model (OECM) requires estimates of the change in imports delivered via tanker.[4] MarketSim therefore uses a post-processing approach to estimate the change in oil tanker imports. Under this approach, MarketSim assumes that all pipeline imports of oil are produced in Canada. Based on this assumption, MarketSim estimates the change in tanker imports as the difference between total imports (estimated as U.S. consumption less U.S. production) and imports from Canada. The model's calculation for imports from Canada is similar to the non-U.S. oil supply formula except with its own parameter, elasticity, and adjustment rate.

$$Q_{Soc,t} = B_{oc,t} \cdot P_{o,t}^{\eta_{oc}} + (1-\gamma_{Soc})Q_{Soc,t-1}$$

where

$Q_{Soc,t}$ represents the quantity of Canadian pipeline oil imports supplied at time *t*,
$B_{oc,t}$ is a constant,
η_{oc} is the long-run elasticity of Canadian pipeline oil imports, and
γ_{Soc} is the rate at which Canadian pipeline oil import supply adjusts.

5.6 U.S. Crude Oil Exports

As described above, MarketSim models oil as a global market with supply and demand specified separately for the U.S. and the rest of the world. To facilitate the estimation of changes in oil exports, MarketSim's demand equations specify the three categories of non-U.S. demand identified above: (1)

[4] The No Action Alternative is defined as the scenario in which BOEM holds no OCS oil and gas lease sales during the 5-year period covered by the program or, in other words, in which the No Sale Option is selected for each program area.

non-U.S. demand for U.S. crude oil, (2) non-U.S. demand for U.S. refined petroleum products, and (3) non-U.S. demand for non-U.S. oil. The first of these items represents U.S. crude oil exports. Therefore, to estimate the impact of a given E&D scenario on U.S. crude oil exports, MarketSim calculates the difference between non-U.S. demand for U.S. crude oil between the E&D scenario and the model's baseline projection.

While this method for estimating the change in U.S. crude oil exports is incorporated into MarketSim's balancing equations, it does not distinguish between exports of OCS crude oil and exports of crude from other sources. Modeling crude oil exports at this level of detail would require information on the quality of OCS crude relative to other crudes (i.e., API gravity and sulfur content) and various location-specific factors that may influence the relative cost of refining different U.S. crudes domestically versus exporting them to non-U.S. refineries. Incorporating these details into MarketSim's balancing equations is not currently feasible.

Nevertheless, to approximate OCS crude oil exports, MarketSim includes a series of post-processing calculations that parse the model's estimates of the change in crude oil exports into crude oil produced on the OCS and crude oil produced by other sources. These post-processing calculations are based on the assumption that export is most likely for those types of crude oil that are imported in small quantities relative to the total amount (of that oil type) used as feedstock by U.S. refineries. For the purposes of these post-processing calculations, oil type is defined according to API gravity, as this is the only metric of oil quality for which BOEM has data across all OCS crude oils. More specifically, these post-processing calculations distinguish between heavy crude (API gravity less than 27), medium crude (API gravity greater than or equal to 27 but less than 35), and light crude (API gravity greater than or equal to 35).

The specific steps in the post-processing calculations are as follows:

- Based on recent EIA data on crude oil production and crude oil imports by API gravity category (examined as a proxy for U.S. refinery feedstock; see Table 1), MarketSim assumes that light crude produced on the OCS may be exported but not medium or heavy crude. This reflects the fact that U.S. imports for heavy and medium crudes are fairly large (86 and 47 percent, respectively) relative to the total amount used by U.S. refineries. For light crudes, however, imports represent only 10 percent of the total feedstock for U.S. refineries.

Table 1. U.S. Crude Oil Production and Imports by API Gravity Category

API GRAVITY TYPE	TOTAL IMPORTS (THOUSANDS OF BARRELS) [A]	PRODUCTION (THOUSANDS OF BARRELS) [B]	TOTAL (THOUSANDS OF BARRELS) [C=A+B]
Heavy	1,607,176	261,927	1,869,103
Medium	836,060	960,881	1,796,941
Light	244,173	2,181,004	2,425,177
TOTAL	**2,687,409**	**3,403,812**	**6,091,221**

Data Sources: Import data presented here are derived from EIA (2015a). Production data by API gravity category derived from EIA (2015b).

- Due to uncertainty regarding the exact percentage of light OCS crude likely to be exported, MarketSim specifies this percentage as a range, with a low end of 25 percent and a high end of 75 percent. These values are applied to all light crude oil included in the user-specified E&D scenario.
- If either of the resulting values exceeds the total change in crude exports estimated by MarketSim, the estimate is capped at the total change in exports (i.e., so that the change in OCS crude oil exports does not exceed the total change in exports estimated by MarketSim).

5.7 U.S. Exports of Refined Petroleum Products

MarketSim estimates U.S. exports of refined petroleum products based on the specification of non-U.S. demand for refined petroleum products in the model's balancing equations.[5] For a given E&D scenario, the change in U.S. refined product exports is equal to the estimated change in non-U.S. demand for U.S. refined petroleum products. This approach is similar to that outlined above for U.S. exports of crude oil, which MarketSim estimates based on the change in non-U.S. demand for U.S. crude oil.

As a post-processing calculation to MarketSim's specification of the new market equilibrium, the model parses the estimated change in refined product exports between refined products derived from OCS oil and refined products derived from other sources. To make this distinction, MarketSim assumes that the probability that a given barrel of refined product from U.S. refineries is derived from OCS crude oil is proportional to OCS oil's total share of the feedstock used by U.S. refineries (i.e., OCS oil used as feedstock divided by the total feedstock amount). Based on this assumption, the quantity of refined product exports derived from OCS crude is estimated as follows:

$$Q_{R,X,OCS} = F_{OCS} \times Q_{RL,X}$$

where

$Q_{R,X,OCS}$ is the change in refined product exports derived from OCS crude oil.
F_{OCS} is OCS crude oil's share of total U.S. refinery feedstock.
$Q_{RL,X}$ is MarketSim's estimate of the change in U.S. refined product exports.

Applying this approach requires information on OCS crude oil as a share of U.S. refinery feedstock (F_{OCS} in the above equation). To derive F_{OCS}, MarketSim would ideally use the projected amount of OCS crude oil used by U.S. refineries and the projected amount of feedstock that these refineries use. These specific projections, however, are not readily available. In the absence of such data, MarketSim approximates OCS crude as a share of total refinery feedstock as follows, based on MarketSim projections under the E&D scenario:

$$\boldsymbol{F_{OCS} = \frac{Q_{o,off}}{Q_{o,on} + Q_{o,off} + Q_{o,ni}}}$$

---

[5] As noted above, this category of non-U.S. demand represents one of three included in the model. The other two categories are non-U.S. demand for U.S. crude oil and non-U.S. demand for non-U.S. oil.

where

F_{OCS} is OCS crude oil's share of total U.S. refinery feedstock.

$Q_{o,off}$ is offshore crude oil production in the U.S. projected by MarketSim under the E&D scenario over the model's full analytic time horizon.

$Q_{o,on}$ is onshore crude oil production in the U.S. projected by MarketSim under the E&D scenario over the model's full analytic time horizon.

$Q_{o,ni}$ is U.S. net imports of oil projected by MarketSim under the E&D scenario over the model's full analytic time horizon.

The numerator on the right-hand side of this equation approximates OCS crude used as feedstock at U.S. refineries (because the U.S. exports a relatively small portion of the crude oil it produces), and the denominator represents an approximation of total U.S. refinery feedstock. MarketSim uses projections from the E&D scenario to populate this equation rather than baseline EIA data because onshore and offshore production quantities, as well as net imports, may change significantly under a given E&D scenario relative to the baseline.

MarketSim applies this approach after the model converges on a new market equilibrium and estimates new world oil prices, by year ($P_{o,t}$).

6. Natural Gas Market

MarketSim represents the U.S. natural gas market with exports and imports. This stands in contrast to the oil market, which MarketSim simulates as a global market. Natural gas use for electricity generation is represented in the section on electricity below. The equations that follow specify MarketSim's estimation of U.S. natural gas demand, demand for U.S. natural gas exports, and U.S. natural gas supply.

6.1 U.S. Natural Gas Demand

$$Q_{Dgi,t} = A_{gi,t} \cdot P_{g,t}^{\eta_{gi}} \cdot \prod_{j} P_{j,t}^{\eta_{gji}} + (1 - \gamma_{Dgi}) Q_{Dgi,t-1}$$

for each U.S. end-use sector i; and $j = o$ (oil), c (coal), and e (electricity) where

$Q_{Dgi,t}$ represents the quantity of natural gas demanded in sector i at time t,
$A_{gi,t}$ is a constant calibrated to baseline data,
$P_{g,t}$ is the price of natural gas at time t,
η_{gi} is the long-run price elasticity of natural gas demand in sector i,
$P_{j,t}$ is the price of energy source j at time t,
η_{gji} is the long-run elasticity of demand for natural gas with respect to the price of energy source j in sector i, and
γ_{Dgi} is the rate at which demand for natural gas in sector i adjusts.

The U.S. natural gas demand sectors represented in MarketSim include the residential, commercial, industrial, and transportation sectors.

6.2 Demand for U.S. Natural Gas Exports

$$Q_{Dgx,t} = A_{gx,t} \cdot P_g^{\eta_{gx}} + (1-\gamma_{Dgx})Q_{Dgx,t-1}$$

where

$Q_{Dgx,t}$ represents the quantity of U.S. natural gas exports at time t,
$A_{gx,t}$ is a constant calibrated to baseline data,
η_{gx} is the long-run price elasticity of export demand for U.S. natural gas, and
γ_{Dgx} is the rate at which export demand for natural gas adjusts.

U.S. natural gas exports are dependent only upon the domestic price of natural gas and no other prices, domestic or international.

6.3 U.S. Natural Gas Supply

$$Q_{Sgu,t} = B_{gu,t} \cdot P_{g,t}^{\eta_{gu}} + (1-\gamma_{Sgu})Q_{Sgu,t-1}$$

for each domestic and imported source, u where

$Q_{Sgu,t}$ represents the quantity of natural gas supplied to the U.S. market from domestic or imported source u at time t,
$B_{gu,t}$ is a constant calibrated to baseline data,
η_{gu} is the long-run elasticity of natural gas supply to the U.S. market from source u, and
γ_{Sgu} is the rate at which natural gas from source u adjusts.

Natural gas production categories included in MarketSim are (1) lower 48 conventional, (2) lower 48 unconventional, (3) Alaska, (4) offshore, (5) other, (6) pipeline imports, and (7) tanker imports.

7. Coal Market

MarketSim represents the U.S. coal market with exports and imports. Coal use for electricity generation is represented in the section on electricity below. The equations that follow present the model's estimation of U.S. coal demand, demand for U.S. coal exports, and U.S. coal supply.

7.1 U.S. Coal Demand

$$Q_{Dci,t} = A_{ci,t} \cdot P_{c,t}^{\eta_{ci}} \cdot \prod_j P_{j,t}^{\eta_{cji}} + (1-\gamma_{Dci})Q_{Dci,t-1}$$

for each U.S. end-use sector i; and $j = g$ (gas), o (oil), and e (electricity) where

$Q_{Dci,t}$ represents the quantity of coal demanded in sector i at time t,
$A_{ci,t}$ is a constant calibrated to baseline data,
$P_{c,t}$ is the price of coal at time t,
η_{ci} is the long-run price elasticity of coal demand in sector i,
$P_{j,t}$ is the price of energy source j at time t,
η_{cji} is the long-run elasticity of demand for coal with respect to the price of energy source j in sector i, and
γ_{Dci} is the rate at which demand for coal in sector i adjusts.

Other than the electricity sector, whose coal demand is modeled separately, MarketSim's domestic demand sectors for coal include industrial and other.

7.2 Demand for U.S. Coal Exports

$$Q_{Dcx,t} = A_{cx,t} \cdot P_c^{\eta_{cx}} + (1-\gamma_{Dcx})Q_{Dcx,t-1}$$

where

$Q_{Dcx,t}$ represents the quantity of U.S. coal exports at time t,
$A_{cx,t}$ is a constant calibrated to baseline data,
η_{cx} is the long-run price elasticity of export demand for U.S. coal, and
γ_{Dcx} is the rate at which export demand for coal adjusts.

Exports are dependent only upon the domestic price of coal. No other energy prices, domestic or international, affect exports of coal.

7.3 U.S. Coal Supply

$$Q_{Scu,t} = B_{cu,t} \cdot P_{c,t}^{\eta_{cu}} + (1-\gamma_{Scu})Q_{Scu,t-1}$$

for each domestic and imported source, u where

$Q_{Scu,t}$ represents the quantity of coal supplied to the U.S. market from domestic or imported source u at time t,
$B_{cu,t}$ is a constant calibrated to baseline data,
η_{cu} is the long-run elasticity of coal supply to the U.S. market from source u, and
γ_{Scu} is the rate at which coal from source u adjusts.

8. Electricity Market

MarketSim represents the U.S. electricity market and models U.S. exports and imports of electricity as net imports. The electricity sector in MarketSim also provides additional demand for oil, natural gas and coal. The equations below present MarketSim's approach for estimating U.S. electricity demand, U.S. electricity supply, and demand for fossil fuels for electricity production.

8.1 U.S. Electricity Demand

$$Q_{Dei,t} = A_{ei,t} \cdot P_{e,t}^{\eta_{ei}} \cdot \prod_j P_{j,t}^{\eta_{eji}} + (1-\gamma_{Dei})Q_{Dei,t-1}$$

for each U.S. end-use sector i; and $j = g$ (gas), c (coal), and o (oil) where

$Q_{Dei,t}$ represents the quantity of electricity demanded in sector i at time t,
$A_{ei,t}$ is a constant calibrated to baseline data,
$P_{e,t}$ is the price of electricity at time t,
η_{ei} is the long-run price elasticity of electricity demand in sector i,
P_j is the price of energy source j,
η_{eji} is the long-run elasticity of demand for electricity with respect to the price of energy source j in sector i, and
γ_{Dei} is the rate at which demand for electricity in sector i adjusts.

The U.S. demand sectors for electricity in MarketSim include (1) residential, (2) commercial, (3) industrial, (4) transport, and (5) other.

8.2 U.S. Electricity Supply

MarketSim uses separate approaches for the estimation of electricity derived from fossil fuels and electricity derived from other sources. While the quantity of electricity generated from fossil fuels is dependent on fossil fuel prices, changes in these prices do not factor into the generation of electricity from non-fossil energy sources. To account for this difference in the economics of electricity generation for different types of power producers, MarketSim specifies electricity supply as follows:

$$Q_{Sej,t} = C_{j,t} \cdot (P_{e,t} / P_{j,t})^{\eta_{ej}} + (1-\gamma_{Sej})Q_{Sej,t-1}$$ for j = oil, natural gas and coal

$$Q_{Sel,t} = C_{l,t} \cdot P_{e,t}^{\eta_{el}} + (1-\gamma_{Sel})Q_{Sel,t-1}$$ for l = nuclear, hydro, wind, solar, other electric, net imports

where

$Q_{Sej,t}$ represents the quantity of electricity supplied from fossil fuel energy source j at time t,
$Q_{Sel,t}$ represents the quantity of electricity supplied from source l at time t,
$C_{j,t}$ and $C_{l,t}$ are constants calibrated to baseline data,
$P_{e,t}$ is the price of electricity at time t,
$P_{j,t}$ is the price of fossil fuel energy source j at time t,
η_{ej} is the long-run elasticity of electricity supply from fuel j,
η_{el} is the long-run elasticity of electricity supply from source l,
γ_{Sej} is the rate at which electric power from fossil energy j adjusts, and
γ_{Sel} is the rate at which electric power from source l adjusts.

8.3 Demand for Fossil Fuel Energy to Produce Electricity

$$Q_{Dje,t} = K_{j,t} \cdot Q_{Sej,t} \qquad \text{for } j = \text{oil, natural gas and coal}$$

where $Q_{Dje,t}$ represents the quantity of energy source j used to produce electricity at time t and $K_{j,t}$ is a constant.

9. Model Calibration

For a given set of elasticities, adjustment parameters, market quantities, and prices in the baseline projection, MarketSim uses the series of supply and demand equations outlined above to calculate the parameters A, B, C, and K in these equations. These parameters, having been calculated on the baseline projection equilibrium state, calibrate the model formulas directly to the market conditions observed in the baseline projection data. MarketSim then uses these parameters as constants in the simulation supply and demand formulas that equilibrate all four fuel markets under a given E&D scenario.

The model automatically updates the calibration parameters to match new baseline projection data immediately when entered into the baseline projection worksheet tables.

10. Equilibrium

The equilibration calculation of MarketSim selects $P_{o,t}$, $P_{g,t}$, $P_{c,t}$ and $P_{e,t}$ for each period t such that the quantity of oil, natural gas, coal, and electricity demanded equals the quantity supplied in each period t:

$$Q_{Doe,t} + Q_{Dox,t} + \sum_i Q_{Doi,t} = Q_{Soy,t} + \sum_u Q_{Sju,t} \qquad \text{World Oil Market}$$

$$Q_{Dge,t} + \sum_i Q_{Dgi,t} + Q_{Dgx,t} = \sum_u Q_{Sgu,t} \qquad \text{U.S. Natural Gas Market (with exports and imports)}$$

$$Q_{Dce,t} + \sum_i Q_{Dci,t} + Q_{Dcx,t} = \sum_u Q_{Scu,t} \qquad \text{U.S. Coal Market (with exports and imports)}$$

$$\sum_i Q_{Dei,t} = \sum_j Q_{Sej,t} + \sum_l Q_{Sel,t} \qquad \text{U.S. Electricity Market (with net imports)}$$

To initiate the equilibration process for a given E&D scenario, MarketSim first adds the incremental increase in OCS production to the oil and gas supply terms in the above equilibrating equations. Because supply has changed, markets are not in equilibrium under the original baseline prices. Using Excel's solver function, MarketSim then uses reduced gradient methods to iterate through several combinations of the four fuel prices until it can bring all four fuel markets' supply and demand into equilibrium. During this process, all simulated supply and demand values are calculated using the same elasticity, adjustment, and parameter values used to represent the baseline. When zero disparity between supply and demand across all four fuel markets is achieved, MarketSim saves the market-clearing prices and proceeds to the next year to perform the same equilibration.

11. Adjustment Rates and Elasticities

All elasticities and adjustment rates in MarketSim have default values that are obtained from the literature, inferred from NEMS output, or obtained through expert consultation with energy economists in academia. In addition, all values can be edited easily by the user to incorporate the user's best judgment for any given elasticity value or adjustment rate. Further, all default values can be automatically restored after editing to return the values to their original settings. The sections below document the derivation of the default adjustment rates and elasticities included in MarketSim.

11.1 Derivation of Default Adjustment Rates

As described above, MarketSim uses a series of adjustment rates to capture the transition from short-run to long-run market effects. These adjustment rates account for the portion of demand or supply that is allowed to change per time period. In the case of this model, the time period is one year. No data on the adjustment rates for specific energy sources were readily available. In the absence of such data, MarketSim uses expert input from Dr. Stephen Brown of the University of Las Vegas (UNLV) for several adjustment rates. For most values however, MarketSim assumes that the adjustment rate is related to the retirement of energy producing and consuming capital (i.e., equipment that produces energy or consumes energy), as indicated by its lifespan. Based on lifespan values obtained from the literature, adjustment rates are calculated as follows:

$$\gamma_{Dji} = \frac{1}{L_{Dji}} \qquad \text{or} \qquad \gamma_{Sju} = \frac{1}{L_{Sju}}$$

where γ_{Dji} is the rate at which the quantity demanded adjusts in each U.S. end-use sector i for each fuel j and L_{Dji} is the lifespan of the main consumption capital in each submarket. Similarly, γ_{Sju} is the rate at which the quantity supplied adjusts from each production source u for each fuel j and L_{Sju} is the lifespan of the main production capital equipment in each submarket.

Tables 2 and 3 present the adjustment rates included in MarketSim as well as the lifespan values supporting each adjustment rate.

For non-U.S. oil demand, MarketSim assumes an adjustment rate equal to that for the U.S. transport sector, under the assumption that transportation-related uses dominate oil consumption in non-U.S. markets.

Table 2. Adjustment Rates for Energy Demand

SECTOR	ADJUSTMENT RATE	SUPPORTING LIFESPAN INFORMATION
Oil		
Residential	0.06	Adjustment rate based on low end of residential oil boiler lifespan range (18 years) presented in EIA (2018). The low end of the lifespan range from this document was chosen to allow for the possibility of early boiler replacement in response to changes in energy prices.
Commercial	0.04	Value reflects 25-year service life of oil-fired commercial boilers obtained from EIA (2018).
Industrial	0.04	Adjustment rate reflects the low end of the 25 to 40 year life of industrial oil-fired boilers as reported in International Energy Agency (2010). The low end of the lifespan range from this document was chosen to allow for maximum energy substitution.
Transport	0.09	Value reflects median age of automobiles in operation in the U.S. (11.8 years), as reported in Bureau of Transportation Statistics (2019). Median age used rather than lifespan to allow for greater demand response to price changes within MarketSim.
Non-U.S. Demand for U.S. Refined Product Exports	0.09	Assumed to be same as value for U.S. transportation sector, under the assumption that transportation-related uses are dominant in non-U.S. markets.
Non-U.S. Demand for U.S. Crude Oil Exports	0.09	Assumed to be same as value for U.S. transportation sector, under the assumption that transportation-related uses are dominant in non-U.S. markets.
Non-U.S. Demand for non-U.S. Oil	0.09	Assumed to be same as value for U.S. transportation sector, under the assumption that transportation-related uses are dominant in non-U.S. markets.
Natural Gas		
Residential	0.05	Adjustment rate based on low end of residential gas boiler lifespan range (20 years) presented in EIA (2018). The low end of the lifespan range from this document was chosen to allow for the possibility of early boiler replacement in response to changes in energy prices.
Commercial	0.04	Value reflects 25-year service life of gas-fired commercial boilers obtained from EIA (2018).
Industrial	0.04	Adjustment rate reflects the low end of the 25 to 40 year life of industrial gas-fired boilers as reported in International Energy Agency (2010). The low end of the lifespan range from this document was chosen to allow for maximum energy substitution.
Transport	0.08	Value based on 12-year lifespan for gas powered buses obtained from U.S. Department of Transportation, Federal Transit Administration (2007) and the Scott Institute for Energy Innovation (2017).

Table 2. Adjustment Rates for Energy Demand

SECTOR	ADJUSTMENT RATE	SUPPORTING LIFESPAN INFORMATION
Exports	0.04	Assumed same as industrial value.
Electricity		
Residential	0.10	Based on expert input of Dr. Stephen Brown (2011).
Commercial	0.10	Based on expert input of Dr. Stephen Brown (2011).
Industrial	0.20	Based on expert input of Dr. Stephen Brown (2011).
Transport	0.10	Assumed value.
Other	0.10	Assumed value.
Coal		
Industrial	0.04	Adjustment rate reflects the low end of the 25 to 40 year life of industrial coal-fired boilers as reported in International Energy Agency (2010). The low end of the lifespan range from this document was chosen to allow for maximum energy substitution.
Exports	0.04	Assumed same as industrial value.
Other	0.04	Assumed same as industrial value.

Table 3. Adjustment Rates for Energy Supply

SECTOR	ADJUSTMENT RATE	SUPPORTING LIFESPAN INFORMATION
Oil		
Lower 48 Onshore (Conventional)	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
Lower 48 Onshore (Tight)	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
Lower 48 Offshore	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
Alaska Onshore	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
Alaska Offshore	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
Other	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
Biodiesel	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
Rest of World	0.15	Based on expert input of Dr. Stephen Brown, UNLV (2011).
Pipeline Imports	0.15	Assumed to be same as other oil categories.
Natural Gas		
Lower 48 Conventional	0.15	Adjustment rate based on lifespan of 5 to 10 years for conventional gas production as reported by Encana in U.S. Department of Interior, National Park Service (2008).
Lower 48 Unconventional	0.30	Based on expert input of Dr. Stephen Brown, UNLV (2011).
Lower 48 Offshore	0.15	Assumed to be same as Lower 48 Conventional.
Alaska Onshore	0.15	Assumed to be same as Lower 48 Conventional.
Alaska Offshore	0.15	Assumed to be same as Lower 48 Conventional.
Other	0.15	Assumed to be same as Lower 48 Conventional.
Imports - Pipeline	0.15	Assumed to be same as Lower 48 Conventional.
Imports – Liquefied Natural Gas (LNG)	0.15	Assumed to be same as Lower 48 Conventional.
Electricity		
Oil	0.03	Adjustment rate based on an assumed 30-year lifespan for oil-fired electricity generation units, consistent with the values below for natural gas and coal units.

Table 3. Adjustment Rates for Energy Supply

SECTOR	ADJUSTMENT RATE	SUPPORTING LIFESPAN INFORMATION
Natural Gas	0.03	Adjustment rate reflects 30-year gas-fired power plant life, as reported in U.S. DOE, National Energy Technology Laboratory (2007, 2019).
Coal	0.03	Adjustment rate reflects 30-year coal-fired power plant life, as reported in U.S. DOE, National Energy Technology Laboratory (2007, 2019).
Nuclear	0.02	Based on 60-year nuclear power plant life, as reported in U.S. DOE EIA (2010).
Hydro	0.01	Value reflects assumed 75-year lifespan of hydroelectric facilities, based on the 50 to 100 year range presented in US Geologic Survey (2010).
Wind (Offshore)	0.05	Value assumes 20-year lifespan for wind power units, based on American Wind Energy Association (undated) and U.S. DOE (2015).
Wind (Onshore)	0.05	
Solar	0.04	Adjustment rate reflects an effective 25-year lifespan for solar systems. This reflects the 30-year operational life of crystalline modules, adjusted for the approximate 20 percent output degradation over a module's lifetime. Lifespan and output degradation estimates from Jordan and Kurtz (2012).
Other Electric	0.031	Adjustment rate is the average of the values for electricity produced from oil, natural gas, coal, nuclear energy, hydro, solar, and wind.
Imports	0.026	Adjustment rate is the average of the values for electricity produced from oil, natural gas, coal, nuclear energy, and hydro. Solar and wind were not included in the calculation under the assumption that little solar or wind energy is imported into the United States.
Coal		
Domestic	0.10	Based on expert input of Dr. Stephen Brown, UNLV (2011).
Imports	0.10	Based on expert input of Dr. Stephen Brown, UNLV (2011).

11.2 Selection of Default Elasticity Values

To the extent possible, MarketSim relies upon demand and supply elasticities obtained from peer-reviewed studies in the empirical economics literature. Using peer-reviewed values is central to ensuring that MarketSim's simulation of energy markets reflects the best information available on the demand and supply responses that result from changes in energy prices. As suggested above, in the few cases where peer-reviewed values are not available, elasticity estimates were derived from NEMS outputs or from expert input provided by Dr. Seth Blumsack of Pennsylvania State University, Dr. Charles Mason of the University of Wyoming, and Dr. Gavin Roberts of Weber State University.

11.2.1 Demand Elasticities

To capture the complex interactions between different segments of U.S. energy markets, MarketSim requires own-price and cross-price demand elasticities for every energy source included in the model. For each major energy consuming sector (e.g., the residential sector), BOEM strove to use own-price and cross-price demand elasticities from the same empirical study to ensure that a sector's simulated responses to energy price changes were based on price sensitivities derived from the same methods and data. The selection of demand elasticities also considered the quality of the estimates produced by each study. BOEM's assessment of quality for individual elasticity estimates considered, among other factors, (1) whether they are statistically significant, (2) methods by which they were derived, and (3) the richness of the data supporting each estimate (e.g., whether they are based on a multi-year panel or reflect energy market data for a single year).

Based on these criteria, MarketSim relies heavily on own-price and cross-price demand elasticities from Serletis *et al.* (2010) for the residential and commercial sectors and Jones (2014) for the industrial sector. Serletis *et al.* (2010) investigate inter-fuel substitution possibilities for energy demand across four fuels (i.e., oil, gas, electricity, and coal) using EIA data for the 1960–2007 period. Based on these data, Serletis *et al.* estimated own-price and cross-price elasticities for the commercial, residential, and industrial sectors, using a flexible translog functional form. Across most sectors, Serletis *et al*. produced statistically significant elasticity values of the expected sign.

Jones (2014) focuses on inter-fuel substitution in the industrial sector, using EIA data for the 1960–2011 period for the same fuels included in Serletis *et al.* (2010) plus biomass. Jones specifies a dynamic linear logit model to estimate own-price and cross-price elasticities, and within this framework, estimates both short-run and long-run elasticities. In addition, to assess the role of biomass in industrial sector inter-fuel substitution, Jones develops two sets of models, one including the four fuels traditionally included in industrial sector energy models (i.e., natural gas, oil, coal, and electricity) and another that includes these energy sources plus biomass. Jones finds that the addition of biomass reduces both the own-price and cross-price elasticities of demand for the four traditionally modeled fuels. The effect is most significant for those values associated with electricity. In both models, the four traditional fuels are found to be substitutes with each other with the exception of electricity and oil; the cross-price elasticities for these energy sources are not statistically significant.

Table 4 presents the default own-price and cross-price demand elasticities included in MarketSim for the residential, commercial, industrial, and transport sectors. The table also shows the default elasticity values for miscellaneous demand sectors included in MarketSim (e.g., natural gas demand in U.S. export markets).

Table 4. MarketSim Default Demand Elasticities

	ELASTICITY WITH RESPECT TO CHANGE IN OIL PRICE	ELASTICITY WITH RESPECT TO CHANGE IN GAS PRICE	ELASTICITY WITH RESPECT TO CHANGE IN ELECTRICITY PRICE	ELASTICITY WITH RESEPCT TO CHANGE IN COAL PRICE
***Commercial Sector*[1]**				
Oil	-0.939	0.2	1.08	-
Natural Gas	0.07	-0.296	0.419	-
Electric	0.092	0.041	-0.134	-
Coal	-	-	-	-
***Residential Sector*[1]**				
Oil	-1.002	0.2	1.151	-
Natural Gas	0.07	-0.313	0.507	-
Electric	0.214	0.072	-0.287	-
Coal	-	-	-	-
***Industrial Sector*[2]**				
Oil	-0.264	0.249	0.01	0.090
Natural Gas	0.172	-0.468	0.178	0.050
Electric	0.009	0.118	-0.125	0.061
Coal	0.440	0.351	0.652	-1.468
Miscellaneous Demand Categories				
Oil – Transport Sector[3]	-0.300	-	-	-
Oil – Rest of World Demand for U.S. Crude[4]	-0.15	-	-	-
Oil – Rest of World Demand for U.S. Refined Products[4]	-0.15			
Oil – Rest of World Demand for non-U.S. oil[4]	-0.15			
Natural Gas – Transport[5]	-	-1.00	-	-
Natural Gas – U.S. Exports[6]	-	-0.89	-	-
Electricity – Transport[5]	-	-	-1.00	-
Electricity – “Other”[7]	-	-	-0.18	-
Coal – Other[8]	-	-	-	-1.468
Coal – U.S. Exports[5]	-	-	-	-1.00

Notes:

1. Commercial and residential sector values are from Serletis *et al.* (2010), except for the cross-price elasticity for gas in response to oil prices and the cross-price elasticity of oil in response to gas prices. For these latter two values, MarketSim uses demand elasticities from Newell and Pizer (2008). Also, Deryugina *et al.* (2017) estimate a range of residential elasticity values for electricity consistent with the value in Serletis *et al.* (2010).
2. For the industrial sector, MarketSim uses demand elasticities from Jones (2014), except for the cross-price elasticity of electricity in response to oil prices and the cross-price elasticity of oil in response to electricity prices. For these values, MarketSim uses demand elasticities from Serletis *et al*. (2010).
3. Dahl (2012)
4. Huntington *et al*. (2019)
5. Assumed to be -1.00.
6. Dahl (2010)
7. Assumed to be average of own-price elasticity values for industrial, commercial, and residential sectors.
8. Industrial sector value from Jones (2014).

As indicated in the table, MarketSim uses results from Serletis *et al*. (2010) as defaults for the commercial and residential sectors, except for the elasticity of demand for natural gas with respect to the price of oil and the elasticity of demand for oil with respect to the price of natural gas. The estimates for these cross-price elasticities in Serletis *et al.* were of the unexpected sign (negative) and were not statistically significant. Therefore, in lieu of Serletis *et al.*, MarketSim uses results from Newell and Pizer (2008) for these values, for both the commercial and residential sectors. Newell and Pizer (2008) estimate these cross-price relationships for the commercial sector only. While MarketSim would ideally use default values specific to the residential sector, alternative values for these cross-price elasticities were not readily available for the residential sector. Given the similarities between the commercial and residential sectors, MarketSim uses these two cross-price demand elasticities from Newell and Pizer (2008) as a reasonable approximation of the corresponding residential sector values.

For the industrial sector, MarketSim relies almost exclusively on demand elasticities from Jones (2014) as defaults. Although Serletis *et al.* (2010) estimate elasticity values for the industrial sector, the values in Jones (2014) are based on fuel consumption data that exclude fuel use for purposes other than energy (e.g., petroleum products used as lubricants). As described above, Jones (2014) estimates long-run demand elasticities with two specifications, one including biomass as a substitute and another excluding biomass. Based on the statistical significance of the elasticities with biomass included, MarketSim uses the elasticities from the specification that includes biomass. The two exceptions to this are the cross-price elasticity of demand for oil with respect to the price of electricity and the cross-price elasticity of electricity in response to oil prices, as Jones' estimates for these values are not statistically significant. For these values, MarketSim uses estimates from Serletis *et al.* (2010).

Table 4 also shows MarketSim's default own-price demand elasticities for the transport sector and various miscellaneous demand categories. For these categories, MarketSim relies upon elasticity values from multiple sources. For oil demand in the transportation sector, MarketSim uses a U.S.-specific elasticity value obtained from Dahl's (2012) review of price elasticities estimated for more than 100 countries. This value represents the average of the elasticity values identified in the empirical literature. For non-U.S. oil demand, MarketSim applies the value reported in a Huntington *et al.* (2019) review of crude oil demand elasticities in major industrializing economies. For U.S. natural gas exports, MarketSim uses estimates from Dahl's prior (2010) review of the elasticity literature as defaults.

Two categories for which appropriate demand elasticity values were not identified in the literature are miscellaneous coal demand and demand for U.S. coal exports. MarketSim uses the same industrial sector value obtained from Jones (2014) for the former and assumes a value of -1.00 for the latter.

11.2.2 Supply Elasticities

MarketSim includes default supply elasticities, summarized in Table 5, for every production category modeled for a given fuel (e.g, onshore oil production in the lower 48 states). Consistent with the demand elasticities summarized above, several of MarketSim's supply elasticities were obtained from the economic literature, with data sources varying by fuel type.

Table 5. MarketSim Default Supply Elasticities

FUEL	SOURCE	SUPPLY ELASTICITY
Oil	Lower 48 Onshore (Conventional)[1]	0.93
	Lower 48 Onshore (Tight)[1]	0.73
	Lower 48 Offshore[2]	0.19
	Alaska Onshore[3]	0.42
	Alaska Offshore[3]	0.58
	Other[2]	0.67
	Biodiesel[4]	0.24
	Rest of World[2]	0.28
	Canadian Pipeline Imports[2]	0.38
Natural Gas	Lower 48 Conventional[5]	0.75
	Lower 48 Unconventional[5]	0.68
	Lower 48 Offshore[6]	0.19
	Alaska Onshore[3]	1.29
	Alaska Offshore[3]	1.29
	Other[7]	0.51
	Pipeline Imports[8]	0.52
	LNG Tanker Imports[9]	1.00
Electricity	Oil[10]	0.22
	Natural Gas[3]	1.50
	Coal[10]	0.27
	Nuclear[3]	0.53
	Other Electric[3]	0.68
	Hydro[3]	0.05
	Wind Onshore[3]	0.65
	Wind Offshore[3]	0.01
	Solar[3]	2.03
	Imports[3]	0.36
Coal	Domestic[11]	4.39
	Imports[3]	0.16

Notes:
1. Newell & Prest (2019)
2. Expert input from C. Mason, G. Roberts, & S. Blumsack, as documented in Price & Ehrnschwender (2021).
3. Derived from *AEO 2020*.
4. Luchansky and Monks (2009).
5. Newell, Prest & Vissing (2019).
6. Assumed to be the same as Oil, Lower 48 Offshore.
7. Brown (1998).
8. Derived from specialized NEMS runs of the *AEO 2015 provided to DOI by EIA*.
9. Assumed value.
10. Derived from specialized NEMS runs of the *AEO 2018 provided to DOI by EIA*.
11. Derived from the AEO 2020.

For tight oil and other lower 48 onshore oil, MarketSim uses elasticities from a recent study by Newell and Prest (2019). The paper specifically compares the price responses of conventional and unconventional (tight) oil drilling and production. Using micro-data for more than 150,000 oil wells in Texas, North Dakota, California, Oklahoma, and Colorado, Newell and Prest (2019) estimate the elasticity of well drilling and the elasticity of oil production, separately for conventional and unconventional wells. To estimate drilling elasticities, they use multiple model specifications, estimating changes in drilling activity as a function of price in some cases and as a function of revenue in other cases. The production elasticities estimated by Newell and Prest (2019), however, all represent the change in production as a function of the change in revenue, rather than price. To align the supply elasticities in MarketSim with the specification of supply, MarketSim uses the elasticity of well drilling with respect to the oil price from Newell and Prest (2019), which they estimate separately for both conventional and unconventional wells.

Luchansky and Monks (2009) serves as the source for MarketSim's default supply elasticity for domestic biodiesel. This paper uses monthly data for 1997 through 2006 to estimate the market supply and demand for ethanol at the national level. Applying these data to four specifications of supply, Luchansky and Monks (2009) estimated supply elasticities ranging from 0.224 to 0.258. MarktSim uses the midpoint of this range (0.24) as the default supply elasticity for biodiesel.

For a number of oil supply elasticities, MarketSim relies on expert input provided to BOEM by three energy economists: Dr. Charles Mason of the University of Wyoming, Dr. Seth Blumsack of Penn State University, and Dr. Gavin Roberts of Weber State University. BOEM relies on input provided by these experts for the oil supply elasticities related to lower 48 offshore, rest-of-world oil production, Canadian pipeline imports, and other oil production. The input provided by these experts is documented in Price and Ehrnschwender (2021). For oil production in Alaska, MarketSim uses supply elasticities derived from specialized simulations of NEMS, as described in detail below.

For gas production, MarketSim draws on a variety of sources for elasticities, depending on the production source. For domestic onshore conventional and unconventional shale gas production in the lower 48, MarketSim uses values from Newell, Prest & Vissing (2019), who use data from approximately 62,000 gas wells drilled in Texas between 2000-2015 to determine price-responsiveness across the supply process. The study assesses the decision to drill the well, well completion, and produce gas over time and, of these, finds drilling activity to be the most responsive to changes in price. MarketSim makes use of the gas price response values broken out for conventional and unconventional wells, though the study notes that these values may not differ significantly from each other statistically. For offshore production in the lower 48, MarketSim uses the same 0.19 elasticity as for offshore oil production in the lower 48, obtained through the expert input process described in the previous paragraph and documented in Price and Ehrnschwender (2021). For onshore and offshore production in Alaska, MarketSim uses elasticity values derived from specialized simulations of NEMS, as detailed below. For other gas production, MarketSim applies the supply elasticity reported in Brown (1998).

For coal supply, MarketSim uses a supply elasticity derived from annual supply curve data generated by NEMS' Coal Market Module (CMM).[6] The annual supply curve data provided by EIA represent 41 distinct coals for a given year for combinations of coal supply region, sulfur content, mining method, and rank. For example, the Central Appalachia coal supply region has five different supply curves for a given year, representing a mix of low- and medium-sulfur coal, underground and surface mines, and premium and bituminous coals. In addition, the annual supply curve for each of the 41 coals is represented as 11 data points, with each data point representing production at a given price point.

[6] While not publicly available, EIA provided these supply curve data to DOI and provides them to other modelers on a regular basis.

Using the EIA data, supply elasticities were estimated for each of the 41 coal types, for every year between 2019 and 2040. To generate elasticity values, the log-transformed quantity was regressed on the log-transformed price, which yielded the elasticity of supply as the coefficient. Each regression was performed over the three central points of the appropriate supply curve. The following equation displays this regression:

$$\ln\left(Q_{s,t}\right) = \beta_{s,t}\ln\left(P_{s,t}\right) + \beta_0$$

Where:

$Q_{s,t}$ represents the quantity supplied on supply curve *s* in year *t,*

$\beta_{s,t}$ represents the elasticity of supply for supply curve *s* in year *t*[7],

$P_{s,t}$ represents the price of coal on supply curve *s* in year *t*, and

β_0 represents the regression constant.

Running the above regression for each of the coal supply regions yields regionally specific coal supply elasticity values. The national coal supply elasticity value in MarketSim reflects the weighted average of the regional estimates, using coal production by region as weights.

Where appropriate economic research does not exist or could not be obtained for a specific supply elasticity value, projections from the *AEO 2020* low-world price, high-world price, and reference cases were used to infer these values.[8] Elasticity estimates may be inferred from the *AEO* projection for a given year by comparing the differences in energy prices between two scenarios with the differences in energy quantities. For a given energy source and fuel, an annual inferred elasticity value was calculated three times: (1) based on the low oil price case vs. the high oil price case, (2) the low price case vs. the reference case, and (3) the reference case vs. the high price case, for all *AEO 2020* projection years from 2019 through 2050. The formula for this annual inferred elasticity is as follows.

$$\eta_t = \frac{\ln\left(\frac{Q_{A,t}}{Q_{B,t}}\right)}{\ln\left(\frac{P_{A,t}}{P_{B,t}}\right)}$$

Where η_t is the inferred elasticity in year *t*, $Q_{A,t}$ and $Q_{B,t}$ represent the quantities supplied in year *t* for cases *A* and *B* respectively (each case is compared with both of the other cases), and $P_{A,t}$ and $P_{B,t}$ are the prices at time *t* for cases *A* and *B*. The resulting series of inferred elasticities are averaged, excluding extreme outlier results derived from the *AEO* data.[9]

For a limited number of producing sectors, elasticity values were unavailable from the literature and the data generated by the constrained NEMS run or recent editions of the AEO yielded elasticity values that

[7] Coal supply elasticities are also represented as η_{cr} in Equation 1.

[8] In some cases, the supply elasticities were derived from prior releases of the *AEO* rather than *AEO 2020* when results from the 2020 data resulted in unrealistic elasticity values.

[9] More specifically, elasticities were estimated based on differentials between the low-price case and reference case, the reference case and the high-price case, and the low-price case and the high-price case. They then were averaged across these three variants and across years.

appeared unrealistically high or were insufficient to support estimation of a supply elasticity. In such cases, MarketSim uses a default supply elasticity of 1.0.

12. Consumer Surplus in MarketSim

To assess changes in the welfare of U.S. consumers[10] under a given E&D scenario, MarketSim estimates the change in consumer surplus for each of the end-use energy markets included in the model (e.g., residential sector gas, industrial sector oil, etc.). For a given energy source, these changes in consumer surplus reflect changes in both price and quantity relative to baseline conditions. Under the model structure outlined above, price and quantity may change due to shifts in supply functions driven by the E&D scenario itself or from shifts in demand functions associated with cross-price effects. In addition, changes in quantity and price for a given year (relative to the baseline) reflect the assumption in MarketSim that the amount of energy consumed and produced in a given year depends partially on the quantity consumed and produced in the prior year.

MarketSim's estimation of the change in consumer surplus focuses on welfare changes associated with the consumption of energy within the United States. Although the model accounts for international trade in oil, natural gas, electricity, and coal, it distinguishes between U.S. and non-U.S. consumers of each energy source. This is consistent with the structure of the baseline energy demand projections from EIA that serve as the foundation of MarketSim. These projections reflect U.S. consumption within the residential, commercial, industrial, and transportation sectors. MarketSim's assessment of changes in consumer surplus is limited to these specific demand sectors. None of the model's consumer surplus calculations consider changes in consumption in non-U.S. markets.

12.1 Primary Versus Secondary Markets

With four types of energy included in the model (oil, natural gas, electricity, and coal), MarketSim's calculation of the market equilibrium associated with new OCS oil and gas production accounts for spillover effects to other segments of U.S. energy markets. For example, increased OCS oil production would likely reduce oil prices and lead to a reduction in coal demand due to cross-price effects. Changes in this and other indirectly affected markets may also have feedback effects on oil and natural gas markets. Estimating changes in consumer surplus associated with a given E&D scenario therefore requires careful consideration of surplus changes across multiple markets.

To estimate changes in consumer surplus within the model's multi-market structure, MarketSim draws on the approach outlined in Boardman *et al.* (1996).[11] Recognizing that government interventions in one market (i.e., the primary market) may have spillover effects on other markets (i.e., secondary markets), Boardman *et al.* (1996) present a systematic approach for appropriately estimating welfare changes in general equilibrium. Putting the Boardman *et al.* approach in the context of OCS oil and gas production, BOEM's Five-Year Program leads to an outward shift in the supply function within one or more primary markets such as oil and/or natural gas. This shift leads to a price reduction in the primary market, as

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[10] MarketSim was designed to estimate changes in consumer surplus for U.S. consumers only. The model results do not include changes in consumer surplus for foreign consumers.

[11] This approach is highlighted in Boardman et al. (1996), Gramlich (1998), Mohring (1993), Thurman (1991), and Thurman and Wohlgenant (1989).

shown by the change from P_{P0} to P_{P1} in Figure 1. Due to cross-price effects, this reduction in price in the primary market causes the demand function for substitutes to shift inward, as shown in Figure 2, reducing the quantity of substitutes demanded from Q_{S0} to Q_{S1}. As explained in Boardman *et al.* (1996), this reduction in quantity demanded for substitutes does not lead to a change in consumer surplus that is not already reflected in the primary market surplus change (described below), because the location of the demand curve within the primary market reflects the existence of substitutes. Due to the budget constraint faced by consumers, willingness to pay at a given quantity along the primary market demand function reflects the incremental utility derived from consuming more in the primary market, net of the utility lost from reducing consumption in the secondary market. Thus, changes in consumer welfare associated with changes in quantity in the primary market reflect not only the quantity changes in the primary market but also the corresponding quantity changes in secondary markets. Put differently, the demand function in the primary market is located further to the left than it would be in the absence of substitutes. Without substitutes, the quantity demanded by consumers in the primary market would be higher at each price point.

The shift in demand in the secondary market also leads to a reduction in price within that market, from P_{S0} to P_{S1} in Figure 2. As described in Boardman *et al.* (1996), this reduction in price leads to an increase in consumer surplus represented by area $P_{S0}deP_{S1}$ in Figure 2. This surplus change is not reflected in the primary market. Within MarketSim, this area is estimated as two components. For the rectangle $P_{S0}dfP_{S1}$, this portion of consumer surplus is simply $\Delta P \times Q^*$. To calculate the area of *def*, MarketSim calculates the definite integral of D_{S1} over the range [Q^*, Q_{S1}] and subtracts the area of the rectangle Q^*feQ_{S1}.

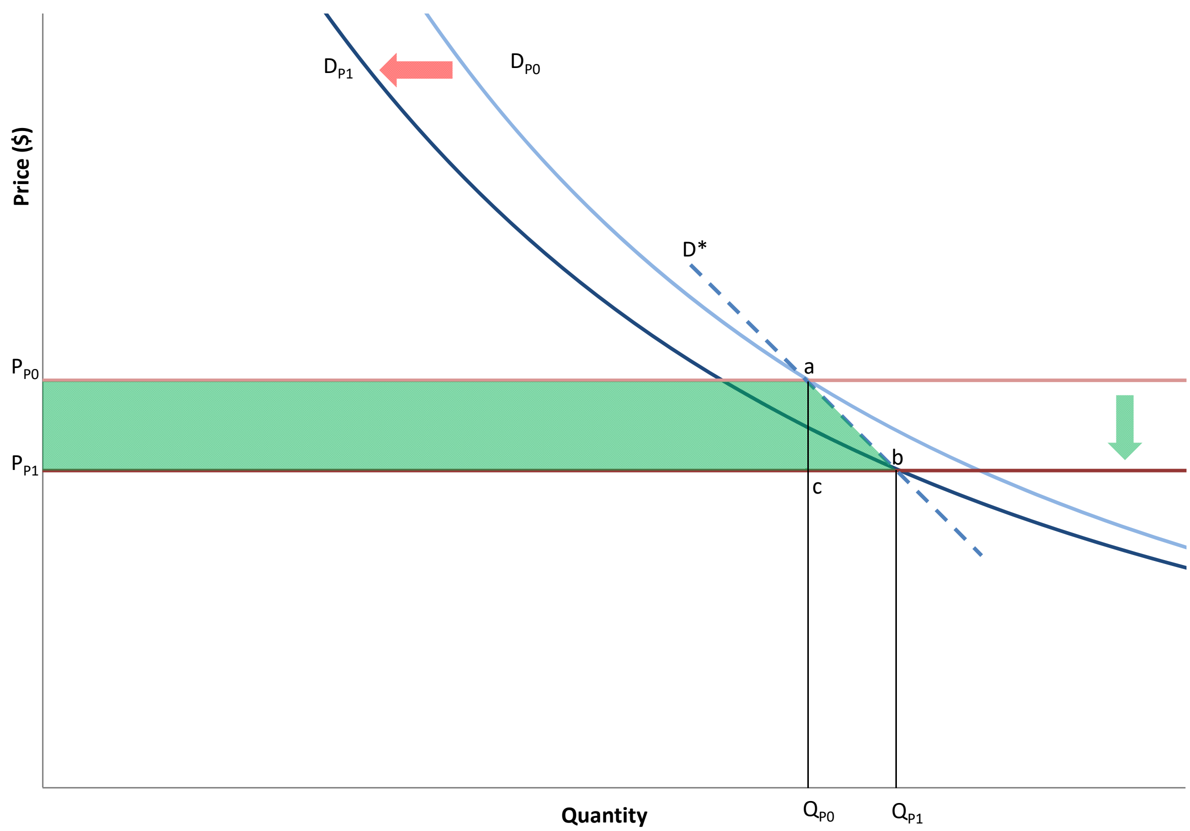

Figure 1. Primary Market Consumer Surplus Change

Boardman *et al.* (1996) suggest a different approach for estimating consumer surplus changes within the primary market. Returning to the context of BOEM's Five-Year Program, the program itself causes a shift in supply, which, as described above, causes a reduction in price for substitutes (see Figure 2). As the price of substitutes decreases, demand within the primary market declines, as represented by the inward shift in demand in Figure 1. Equilibrium in the primary market therefore changes from point *a* in the baseline to point *b* following implementation of the Five-Year Program. Boardman *et al.* (1996) suggest that the associated change in consumer surplus should be estimated along the equilibrium demand curve represented by the line D* connecting points *a* and *b* in Figure 1. Unlike D_{P0} and D_{P1}, which hold the prices of all other goods constant, the equilibrium demand curve shows demand once prices in other markets have fully adjusted to the change in the primary market. Using the equilibrium demand curve, the change in the primary market's consumer surplus includes two components. First, the price effect on the baseline quantity is represented by rectangle $P_{P0}acP_{P1}$, calculated as $\Delta P \times Q_{P0}$. Second, the additional consumer surplus associated with the increase in quantity is calculated as triangle *abc*, calculated as $0.5(\Delta Q \times \Delta P)$. In total, the change in consumer surplus for this primary market is the trapezoid $P_{P0}abP_{P1}$.

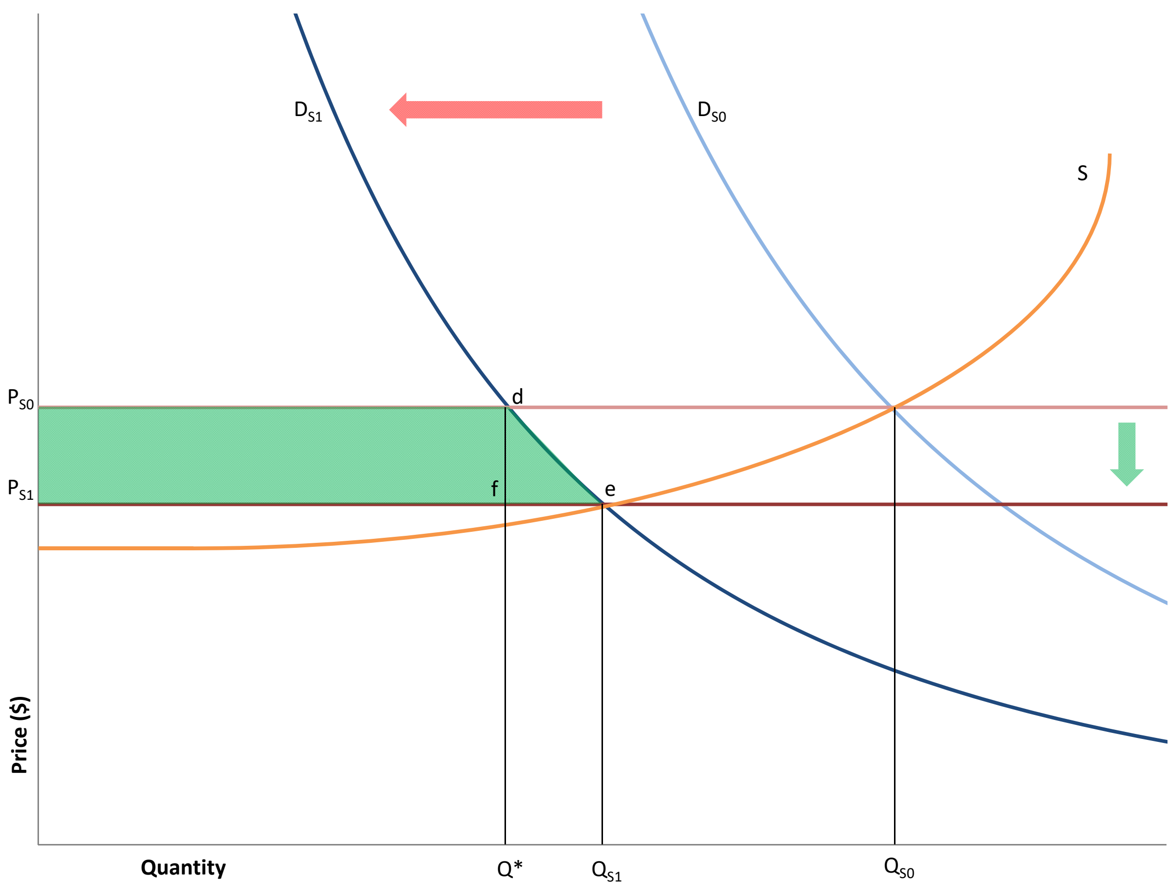

Figure 2. Secondary Market Consumer Surplus Change (reduced

To estimate the changes in consumer surplus associated with BOEM's Five-Year Program, MarketSim applies the approach from Boardman *et al.* (1996) outlined in Figures 1 and 2. One complicating factor in the application of this approach is that oil and natural gas may be both primary and secondary markets. That is, OCS production of oil may affect natural gas markets and OCS natural gas production may affect oil markets. Similarly, because electricity may be produced with OCS natural gas and, to a much lesser extent OCS oil, the electricity market may be both a primary and secondary market.[12] A key distinction between primary and secondary markets in Boardman *et al.* (1996), however, is that primary markets see an increase in the equilibrium quantity demanded while secondary markets experience a reduction in quantity.[13] For the purposes of estimating the change in consumer surplus, MarketSim therefore treats oil, natural gas, or electricity as primary markets if the quantity demanded under the E&D scenario increases relative to the baseline. For example, if the equilibrium quantity of oil in the 2020 transportation market is higher in the E&D scenario than the baseline EIA NEMS projection quantity, the 2020 oil transportation market will be treated as a primary market and its change in consumer surplus will be calculated based on the approach shown in Figure 1. Conversely, if the quantity of oil, natural gas, or electricity demanded decreases from the baseline to the E&D scenario, MarketSim calculates the consumer surplus change based on the secondary market approach.[14]

This rule does not apply to coal which always is treated as a secondary market in MarketSim. Because E&D oil and natural gas production effects on coal markets are only indirect, coal is never considered a primary market for the purposes of MarketSim's consumer surplus change calculations.

12.2 Effects of Persisting Quantity on Consumer Surplus

MarketSim's supply and demand equations include lagged or persisting quantities such that the minimum quantity of fuel demanded or supplied in any given year is a certain percentage of the quantity demanded or supplied, respectively, during the previous year. In cases of large quantities added or removed from the E&D scenario production schedule year-on-year, the lagged structure of the model may result in short-term swings in price in certain markets as the model responds to these changes in OCS production. This sometimes leads to counterintuitive results within the model. For example, in some years, particularly those following a sharp reduction in production associated with the OCS program, the quantity demanded may decline relative to the baseline while price increases. As shown above in Figure 2, however, reductions in demand in secondary markets typically are accompanied by reductions in price instead of an increase—the inward shift in demand reduces both quantity and price.

To estimate the consumer surplus change in secondary markets under these conditions of declining quantity with increasing price, we follow the approach shown in Figure 3. Similar to the situation depicted in Figure 2 where price declines, the approach shown in Figure 3 limits estimation of the change in consumer surplus to effects associated with the change in price projected by MarketSim for the portion

[12] To avoid double counting consumer surplus changes associated with oil and natural gas used for electricity production, MarketSim's estimation of the consumer surplus changes for oil and natural gas does not include oil and gas used for electricity generation. Changes in consumer surplus associated with oil and natural gas used for this purpose are reflected in the model's consumer surplus calculations for electricity consumers.

[13] The opposite would be true for policies that reduce supply.

[14] MarketSim may treat a given market as a primary market one year and as a secondary market in other years. For any given year, MarketSim determines primary/secondary market status based on the change in quantity demanded relative to the baseline.

of the quantity demanded that remains unchanged relative to the baseline, as represented by rectangle $P_{S1}ghP_{S0}$ in Figure 3. Surplus changes associated with the reduction in quantity are reflected in the estimated surplus change in primary markets.[15]

The lagged quantities in MarketSim's demand equations also may lead to situations where consumer surplus decreases following sharp reductions in E&D production after the E&D peak. For example, as E&D production peaks, the quantity of energy demanded increases in response to lower energy prices. After the E&D production peak, however, the subsequent reduction in energy consumption for any given year is limited by the lagged quantities in MarketSim's demand equations and cannot drop below a certain threshold defined by $(1-\gamma)Q_{t-1}$. To meet this demand following the sharp reductions in E&D production, supply must increase from other sources, but an increase in price is necessary to achieve such an increase. Thus, price and the quantity demanded may both increase relative to the baseline, leading to a reduction in consumer surplus. These reactions to sudden increases and decreases can be minimized by smoothing E&D production schedules over time, or by setting all of the adjustment rates (γ values) to 1 in the model.

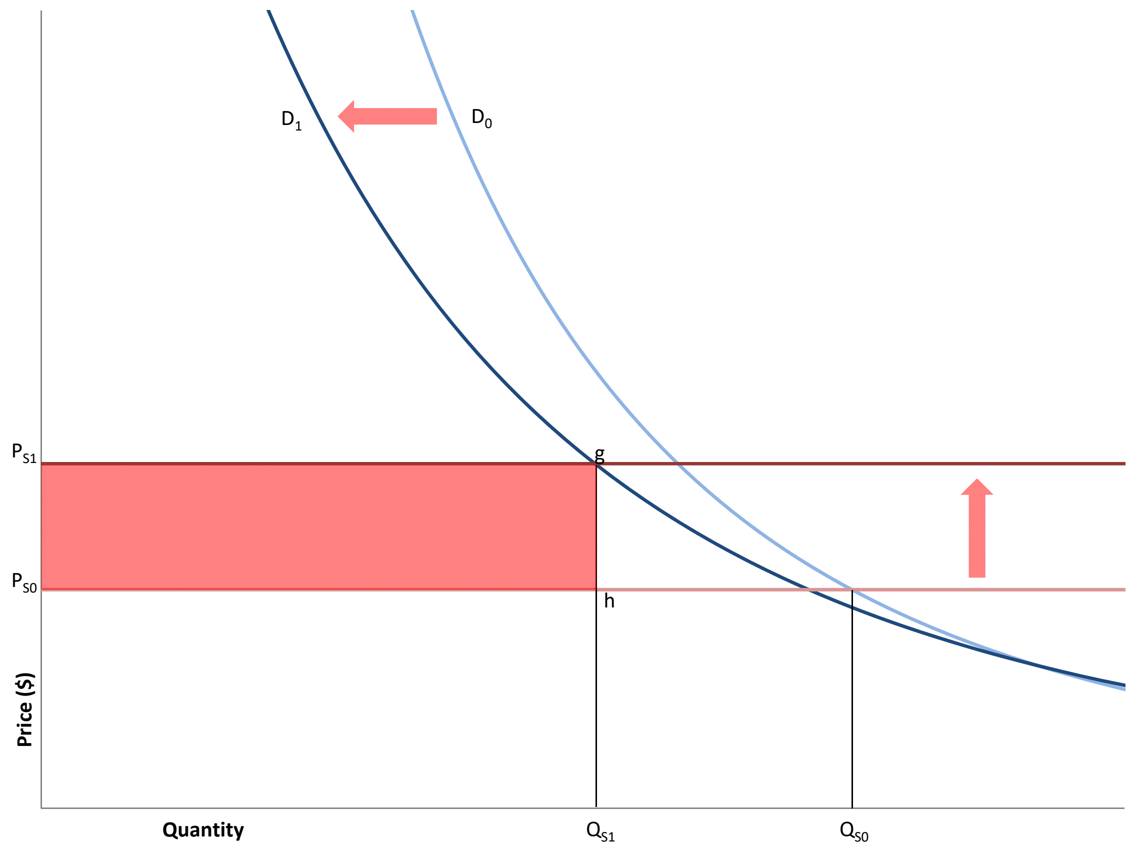

Figure 3. Secondary Market Consumer Surplus Change (reduced quantity, increase in price)

[15] In primary markets with increasing quantity, increased prices imply a consumer surplus loss. MarketSim estimates such losses using the general approach outlined in Figure 1, but estimates a reduction in consumer surplus for the baseline quantity (Q_{P0}) and over the increase in quantity ($Q_{P1}-Q_{P0}$).

12.3 Exclusion of Domestic Producer Surplus Losses

Following the approach described above, MarketSim estimates the full change in consumer surplus associated with a given E&D scenario. This includes transfers in surplus from (or to) energy producers resulting from changes in energy prices. For example, if the price of energy declines as shown above in Figure 1, the portion of the consumer surplus impact represented by rectangle $P_{P0}acP_{P1}$ in Figure 1 is a transfer of surplus from producers to consumers. To the extent that consumer surplus gains such as those represented by rectangle $P_{P0}acP_{P1}$ are a transfer from *U.S.* producers, they do not represent a welfare gain for the U.S., as the gain to U.S. consumers is offset by the loss to U.S. producers. In contrast, transfers from non-U.S. producers to U.S. consumers do represent an increase in U.S. welfare.
To enable model users to estimate changes in U.S. consumer surplus net of transfers from U.S. producers, MarketSim generates an alternative set of consumer surplus estimates that exclude welfare transfers from (or to) U.S. energy producers. To generate these estimates, MarketSim multiplies the portion of the consumer surplus impact that represents a transfer from (or to) producers by the fraction of demand met by non-U.S. sources. In situations where a given energy source is treated as a primary market, the transfer portion of the consumer surplus impact is rectangle $P_{P0}acP_{P1}$ in Figure 1. When MarketSim treats an energy source as a secondary market, the entire change in consumer surplus represents a transfer.

Following this approach, an important step in evaluating consumer surplus net of transfers from domestic producers is estimating the fraction of demand met by non-U.S. sources. Because the specification of supply and demand differs somewhat across oil, gas, electricity, and coal markets in MarketSim (e.g., oil is modeled as a global market, whereas natural gas is modeled for the U.S. market with imports and exports), our approach for estimating the fraction of U.S. demand met by non-U.S. sources varies by energy source, as detailed below.

12.3.1 Oil

MarketSim models the world oil market but distinguishes between supply and demand in the U.S. and in other countries. Based on this information, we estimate the fraction of U.S. oil demand met by non-U.S. sources as follows:

$$L_f = \frac{(D_{L,W} - D_{L,ROW}) - (S_{L,W} - S_{L,ROW})}{(D_{L,W} - D_{L,ROW})}$$

Where L_f = fraction of U.S. oil demand met by non-U.S. sources of supply,
$D_{L,W}$ = global oil demand,
$D_{L,ROW}$ = non-U.S. oil demand,
$S_{L,W}$ = global oil supply, and
$S_{L,ROW}$ = non-U.S. oil supply.

The numerator of this formula represents oil consumed in the U.S. but produced in other countries, estimated as the difference between U.S. demand and U.S. production. The denominator represents U.S. oil demand.

12.3.2 Natural Gas

For natural gas, MarketSim simulates the U.S. market (rather than the global market) but estimates U.S. imports and exports of natural gas. Based on this specification of the market, we estimate the percentage of U.S. natural gas demand met by non-U.S. sources as follows:

$$G_f = \frac{S_{G,I}}{(D_{G,T} - D_{G,X})}$$

Where G_f = fraction of U.S. natural gas demand met by non-U.S. sources of supply,
$S_{G,I}$ = U.S. natural gas imports,
$D_{G,T}$ = Total U.S. natural gas demand, including demand for U.S. natural gas exports, and
$D_{G,X}$ = Demand for U.S. natural gas exports.

12.3.3 Electricity

MarketSim models the U.S. electricity market at the national level and includes net imports in its specification of electricity supply. We therefore estimate the share of U.S. demand satisfied by non-U.S. generation as follows:

$$E_f = \frac{S_{E,NI}}{D_{E,T}}$$

Where E_f = fraction of U.S. electricity demand met by non-U.S. sources of supply,
$S_{E,NI}$ = U.S. net imports of electricity, and
$D_{E,T}$ = total U.S. demand for electricity (including net imports).[16]

12.3.4 Coal

Similar to its treatment of natural gas markets, MarketSim simulates coal as a national market and estimates imports and exports separately (rather than estimating net imports). Based on this model structure, we estimate the percentage of U.S. coal demand met by non-U.S. producers as follows:

$$C_f = \frac{S_{C,I}}{(D_{C,T} - D_{C,X})}$$

Where C_f = fraction of U.S. coal demand met by non-U.S. sources of supply,
$S_{C,I}$ = U.S. coal imports,
$D_{C,T}$ = Total U.S. coal demand, including demand for U.S. exports, and
$D_{C,X}$ = Demand for U.S. coal exports.

[16] Given the structure of MarketSim, the total U.S. demand for electricity is equal to the U.S. electricity supply (including net imports). Thus, the formula for E_f could be re-written with the U.S. supply of electricity in the denominator.

References

American Wind Energy Association. Wind turbine operations & maintenance. http://awea.org/learnabout/publications/upload/O-M-PPR_1-pager-3.pdf.

Boardman AE, Greenberg DH, Vining AR, Weimer D. 1996. Cost-benefit analysis concepts and practice. Upper Saddle River (NJ): Prentice Hall.

Brown SPA. 1998. Global warming policy: some economic implications. Federal Reserve Bank of Dallas Economic Review. Fourth Quarter 1998.

Bureau of Transportation Statistics (2019). Average Age of Automobiles and Trucks in Operation in the United States. https://www.bts.gov/content/average-age-automobiles-and-trucks-operation-united-states

Dahl CA. 2010. Review and critique of elasticities used in the world energy projections plus model. US Department of Energy, Energy Information Administration. Office of Integrated Forecasting and Analysis.

Dahl CA. 2012. Measuring global gasoline and diesel price and income elasticities. Energy Policy. 41: 2–13.

Deryugina, T., MacKay, A., & Reif, J. 2017. The long-run elasticity of electricity demand: Evidence from municipal electric aggregation. *American Economic Journal: Applied Economics Forthcoming*.

[DOE] US Department of Energy. 2015. 2015 Wind Technologies Market Report. https://www.energy.gov/sites/prod/files/2016/08/f33/2015-Wind-Technologies-Market-Report-08162016.pdf

EIA. 2010. Annual Energy Outlook 2010.

EIA. 2015. Annual Energy Outlook 2015: Special constrained NEMS run by EIA for BOEM.

EIA. 2015a. Company level imports. https://www.eia.gov/petroleum/imports/companylevel/archive/.

EIA. 2015b. US crude oil projections to 2025: updated projections of crude types.

EIA. 2018. Annual Energy Outlook 2018: Special constrained NEMS run by EIA for BOEM.

EIA. 2018. Updated Buildings Sector Appliance and Equipment Costs and Efficiencies. https://www.eia.gov/analysis/studies/buildings/equipcosts/pdf/full.pdf

EIA. 2020. Annual Energy Outlook 2020.

Gramlich EM. 1998. A guide to benefit-cost analysis, second edition. Prospect Heights (IL): Waveland Press, Inc.

Gruenspecht H. 2009. Alternate scenarios of energy markets under various offshore crude oil and natural gas resource assumptions. Letter to Walter D. Cruickshank, Acting Director. Mineral Management Service, 4 June.

Huntington, H. G., Barrios, J. J., & Arora, V. 2019. Review of key international demand elasticities for major industrializing economies. *Energy Policy*, *133*, 110878.

[IEA] International Energy Agency. 2010. Technology brief 101: industrial combustion boilers. http://www.iea-etsap.org/web/E-TechDS/PDF/I01-ind_boilers-GS-AD-gct1.pdf.

Industrial Economics, Inc., RPS ASA, Northern Economics, Muller NZ, 2018. Forecasting environmental and social externalities associated with Outer Continental Shelf (OCS) oil and gas development. Volume 1: The 2018 revised Offshore Environmental Cost Model (OECM). US Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2018-066.

Jones CT. 2014. The role of biomass in US industrial interfuel substitution. Energy Policy. 69:122-126.

Jordan, C. & Kurtz, S. 2012. Photovoltaic Degradation Rates: An Analytical Review. National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy12osti/51664.pdf

Luchansky MS, Monks J. 2009. Supply and demand elasticities in the US ethanol fuel market. Energy Economics. 31(3):403-410.

Mohring H. 1993. Maximizing, measuring, and not double counting transportation-improvement benefits: a primer on closed-and open-economy cost-benefit analysis. Transportation Research Part B: Methodological. 27(6):413-424.

National Park Service. 2008. Potential development of the natural gas resources in the Marcellus shale New York, Pennsylvania, West Virginia, and Ohio. US Department of the Interior, National Park Service.

[NETL] National Energy Technology Laboratory. 2007. Cost and performance baseline for fossil energy plants: volume 1: bituminous coal and natural gas to electricity final report. US Department of Energy, National Energy Technology Laboratory.

[NETL] National Energy Technology Laboratory. 2019. Cost and performance baseline for fossil energy plants: volume 1: bituminous coal and natural gas to electricity final report. US Department of Energy, National Energy Technology Laboratory.

Newell RG, Pizer WA. 2008. Carbon mitigation costs for the commercial building sector: Discrete–continuous choice analysis of multifuel energy demand. Resource and Energy Economics. 30(4):527-539.

Newell, R. G., & Prest, B. C. 2019. The unconventional oil supply boom: Aggregate price response from microdata. *The Energy Journal*, *40*(3).

Newell, R. G., Prest, B.C., & Vissing, A. B. (2019) "Trophy Hunting versus Manufacturing Energy: The Price Responsiveness of Shale Gas." *Journal of the Association of Environmental and Resource Economists*. *6*(2).

Personal communication with Stephen P. A. Brown, University of Nevada at Las Vegas, July 2011.

Price, J. C. & Ehrnschwender, D. B. 2021. "MarketSim 2020 Updates – Expert Elasticity Review Summary Memo." Prepared for Charles Paris and Martin Heinze of the Bureau of Ocean Energy Management, 29 April.

Scott Institute for Energy Innovation, Carnegie Mellon University. 2017. Policymaker Guide: Which Alternative Fuel Technology is Best for Transit Buses?

https://www.cmu.edu/energy/education-outreach/public-outreach/17-104%20Policy%20Brief%20Buses_WEB.pdf

Serletis A, Timilsina GR, Vasetsky O. 2010. Interfuel substitution in the United States. Energy Economics. 32(3):737-745.

Thurman WN. 1991. Applied general equilibrium welfare analysis. American Journal of Agricultural Economics. 73(5):1508-1516.

Thurman WN, Wohlgenant MK. 1989. Consistent estimation of general equilibrium welfare effects. American Journal of Agricultural Economics. 71(4):1041-1045.

US Department of Transportation, Federal Transit Administration. 2007. Transit bus life cycle cost and year 2007 emissions estimation. http://www.trb.org/Main/Blurbs/159061.aspx.

US Geologic Survey. 2010. Advantages of hydroelectric power production and usage.