Technical appendix: Integrated economic analysis

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1. Introduction

This report attempts to provide insight into the potential impacts of climate change in a range of economic sectors and at fine temporal and geographical scales. This includes both the immediate physical impact of climate change, as well as its broader economic ramifications. For example, farmers in the Midwest may experience changes in crop and labor productivity (the physical impacts) due to changes in temperature and precipitation. Changes in the value of the agriculture sector output (the direct costs and benefits) will impact a greater number of people as that value is removed from (or added to) the local economy. Finally, macroeconomic effects such as changes in prices, in cross-regional and cross-sectoral investment, and in long-run growth stemming from lost productivity and stranded capital assets may lessen or amplify these direct costs and benefits.

Technical Appendices I, II, and III describe the methodologies used in this report to estimate physical impacts. This appendix describes the methodology used to estimate direct costs and benefits and their broader macroeconomic effects.

2. Direct costs and benefits

The physical impacts of climate change assessed in the American Climate Prospectus are reported as quantity changes relative to current levels. For example, climate-driven changes in labor productivity are measured in terms of full-time equivalent employees, assuming current labor market conditions. In translating these changes in quantity to changes in value, we measure them against current economic structure and prices. Unless otherwise noted, all direct cost and benefit values are presented in real 2011 US Dollars, either total, per capita, or as a share of national, regional, or state economic output in 2012. Economic data is from US Bureau of Economic Analysis (2014a) and US Bureau of Economic Analysis (2014b). In areas where greater sectoral resolution than available in the BEA data was required, we use the more detailed social accounts provided in IMPLAN Group (2011) to distribute BEA totals.

2.1. Agriculture

As described in Technical Appendix II, changes in agricultural yield are converted to changes in agricultural production quantities after incorporating the inter-annual effects of storage and speculation. Output is modeled as an autoregressive process of yields, as estimated from USDA data.

To calculate the direct costs and benefits from changes in production quantity, we assume that a given change in agricultural output results in a proportional change in the value of that sector's gross output in the reference year. The value of impact sector gross output in a given state and year was calculated as the portion of all agriculture output made up by the impacted crop in a given region in the IMPLAN dataset (2011) times national gross output given by BEA (2014a). The potential for crop switching or land use change was not accounted for in calculating direct costs and benefits; instead, areas that experienced changes in productivity, either positive or negative, had that productivity applied to the existing production in that area. The total cost for all agriculture was found by summing the impacts from the component crops.

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2.2. Labor

Changes in labor productivity are weighted by employee hours worked from the county to the NCA region level. To calculate the direct costs and benefits, we assume that the direct effect of a climate-driven labor productivity change is equal to state value added (BEA, 2014b), distributed among high-and low-risk sectors using IMPLAN data (2011) times the change in labor productivity. This is an assumption of zero elasticity of substitution between labor and other inputs, but does not assume the loss of value of other inputs to production. These dynamics are explored in our analysis of possible macroeconomic effects (see section 3).

2.3. Mortality

Changes in mortality in Appendix II are reported as temperature-driven changes in all-cause mortality by age cohort (less than 1, 1 to 44, 45 to 64, and 65+, from Deschênes and Greenstone, 2011 and Barreca et al., 2013).

We use two approaches to assess the direct costs and benefits of these mortality impacts. First, we apply the value of a statistical life (VSL) used by the EPA of $7.9 million as a benchmark estimate of Americans' "willingness-to-pay" to reduce mortality risk. This includes both market and non-market costs. We also employ an alternative valuation technique, in which we estimate the value of full-time-equivalent (FTE) employee-years lost and/or gained due to climate-driven changes in mortality. We estimate this by extrapolating cohort mortality rates, extrapolated to single years of age using national death rates by 5-year cohort (listed in Table D12) and assuming a uniform distribution within each 5-year cohort. To this we apply current labor force participation rates by age cohort. BEA (2014b) state level value added was divided by current state-specific FTE employment to arrive at a value per employee, which was multiplied by state cohort-specific population and the labor participation data to arrive at a time series of expected value lost per mortality in each cohort bin by state. This was discounted at an annual rate of 3% to arrive at a net present value expected loss per death in each cohort and state. This was multiplied by the change in mortality to arrive at an expected value lost for each state and cohort, which was combined to form probabilistic regional and national labor income mortality cost and benefit estimates.

2.4. Crime

Crime impacts are valued using the method described in Heaton (2010). Changes in property and violent crime are multiplied by current crime levels using the FBI's "Crime in the United States" dataset (2012), and the cost estimates, given in 2007 USD, are adjusted to 2011 USD using the BEA national real GDP deflator.

2.5. Coastal impacts

Coastal impacts were derived directly from the process modeling method described in Technical Appendix III. The total costs of climate damages include the average marginal (annual) costs of property falling below sea level, as well as climate-driven changes in average annual loss from hurricanes and other coastal storms, averaged over 20-year periods.

2.6. Energy

The direct costs and benefits of climate-driven changes in energy demand were assessed using RHG-NEMS, a version of the National Energy Modeling System (NEMS), developed by the US Energy Information Administration (2009) for use in the Annual Energy Outlook (see, for example, 2013) and maintained by the Rhodium Group. A detailed description of those methods is given in Technical Appendix III.

3. Macroeconomic effects

The direct costs and benefits described above have broader economic ramifications by changing relative prices, diverting investment, altering trade flows, among other effects. As is discussed in Chapter 14, many approaches have been used to capture these economic dynamics at regional, national, and global scales. A number of researchers have begun employing computable general equilibrium (CGE) economic models using a mixed complementarity problem (MCP) equilibrium (see e.g. Yang et al., 1996; Jorgenson et al., 2004; Abler et al., 2009; Backus et al., 2010). First proposed by Arrow and Debreu (1954), this type of general equilibrium analysis is a branch of economics that represents the modeled system as completely self-contained, allowing feedbacks of changes in technology, factor (labor, capital, or resource) supplies, or any other parameter to spread throughout the economy through changes in prices and quantities in a theoretically consistent manner. Many modern CGE models explicitly represent multiple individually optimizing agents (both consumers and producers) in a unified framework that ensures price and goods equilibria across all regions and sectors in the modeled economy.

We have elected to use a CGE model in this analysis because of the ability to examine the effect of fine spatial, temporal, and sectoral resolution impacts in a way that tracks impacts, and their interaction, through time.

3.1. Computable General Equilibrium (CGE) modeling

There are many varieties of CGE models; one of the most important design distinctions is the method for representing time or change. The simplest type of model is a comparative statics model. This approach represents the current economy as a single-year equilibrium that is shocked by some experiment. This type of analysis was frequently used in early climate impact assessments (for an overview, see Tol, 2008). It is useful for understanding how today's economy would perform in an alternative state of the world, such as one with a much hotter climate, but is unable to estimate the impacts on non-steady-state changes such as impacts to growth from insufficient capital availability after a storm, or overcapitalization of certain industries in periods of declining demand.

A second alternative is an inter-temporal optimization CGE model, originally developed in Ramsey (1928), Cass (1965), and Koopmans (1965), in which a single CGE optimization framework allows agents to substitute between activities in time as well as across sectors and regions. While many variants on this model have since been developed, the central feature of this model is that agents are able to anticipate changes in future prices and may adjust their behavior in each model period to adapt to the future. This type of model is also useful for policy analysis, but with a very different purpose: because agents in this model are perfectly optimizing over the entire model horizon, this model portrays the best-case outcome and is thus useful for finding optimal policies in response to a specific change.

Finally, CGE models may be recursive-dynamic. In this variant, consumers optimize their behavior in each period with knowledge of conditions in that period only, and dynamic equations link decisions in one period to the constraints on behavior in the next period. For example, if in one period it is optimal to spend more and save less, this will result in a lower level of savings to draw on in the next period.

The goal of the American Climate Prospectus is to assess the potential economic impacts of climate change in the United States under current economic and business practices, in order to provide information on how those practices may need to change in the future to reduce climate risk. As such, we chose a recursive-dynamic CGE model to explore the macroeconomic effects of the direct costs and benefits described above.

4. RHG model of the US economy (RHG-MUSE)

RHG-MUSE is a dynamic recursive computable general equilibrium (CGE) model of the US economy. It is written in the GAMS mathematical programming language, with the static core defined in the MCP-specific sublanguage MPSGE, developed by Rutherford (1987). MUSE is solved annually from 2011 to 2099 using the PATH solver (Dirkse and Ferris, 1995), and simulates the growth of the US economy with changes in labor, capital and productivity. The model is calibrated using the 2011 IMPLAN social accounting matrices (SAMs) at state level. The model has 50 regions (for computational reasons, Washington D.C. is considered part of Maryland in this model) and nine sectors.

4.1. Economic data sources

The IMPLAN social accounts used in this analysis are a detailed dataset describing the inputs and outputs of 440 sectors, 4 factors, 9 households, 6 types of government, and an account for corporations, capital additions and deletions, and each of foreign and domestic trade for all 50 US states and Washington, D.C. IMPLAN social accounting matrices (SAMs) are similar to traditional input-output tables, with the exception that they include flows between institutions such as households and government. This enables

Table D1: Sectors used in the MUSE model

Sectors
Agriculture
Indoor Services
Outdoor Services
Infrastructure
Manufacturing
Mining
Energy
Real Estate
Transportation

the tracking of factors (such as labor use by industry and compensation to households) and other flows not included in a traditional I/O table, enabling a comprehensive accounting of all flows in the economy.

The IMPLAN dataset is typically paired with the IMPLAN model, which models the propagation of certain economic changes as they flow through the accounts tables. This methodology is roughly similar to our calculation of direct effects, and does not endogenously represent changes in prices, technology, or growth.

We have incorporated this dataset into our model using an adapted version of Thomas Rutherford's analysis tools implan98 (Rutherford, 2004), IMPLAN2006inGAMS (Rausch, 2008), and IMPLAN2010inGAMS. Our build process reads each state's IMPLAN SAM as an individual state model, validates the data to ensure that all flows balance (each agent, sector, and transfer type must have inputs and outputs sum to zero), and then aggregates the data into a multi-regional national dataset (see table D13 for the full sectoral aggregation scheme). Additional adjustments are made to ensure that domestic trade is balanced across all regions, and that the dataset is internally consistent. At the conclusion of this process, the dataset is in equilibrium; that is, the three criteria for an MCP solution (described in section 4.3.5) are met without a change in prices.

4.2. RHG-MUSE model structure

As is described above, RHG-MUSE employs a hybrid "recursive-dynamic" framework to examine the long-run equilibrium response to climate impacts. Recursive-dynamic models find an equilibrium solution that optimizes agent behavior (subject to the objectives and constraints defined in the model) within a period, which sets prices and quantities that are linked to subsequent periods through dynamic *updating equations*, which govern the calibration data and constraints applied to the optimization problems in subsequent periods. In other words, the simulation progresses from one year to the next, pausing each year to optimize each agent's welfare, then updating the values for the next year with new information and continuing on.

The optimization that takes place each year is a function only of the previous years' events and is only able to change variables pertaining to that year. Therefore, we refer to the set of annual optimization equations as the RHG-MUSE *static core*, to set it apart from the *updating equations* which apply changes derived in the *static core* to subsequent periods.

The structure used to run RHG-MUSE is written in Python and Javascript, the data preparation, run management, and *updating equations* are written in the mathematical programming language GAMS, and the *static core* is written in the GAMS sub-language MPSGE and solved using the PATH GAMS solver (Dirkse and Ferris, 1995). Throughout the following sections, we refer to the mathematical symbols given in the leftmost column of table D2.

Table D2: Symbols used in RHG-MUSE

Indexing sets:

r	50 states - DC combined with MD
s	9 sectors, given in Table D1
g	9 goods, 1 for each sector, interchangeable with s
m	Local (loc), domestic ($dtrd$) and international ($ftrd$)
t	Domestic ($dtrd$) and international ($ftrd$)
y	89 time periods, running from 2011 to 2099
a	Single years of age, from 0 to 65

Static parameters:

Base-year data	
k_r^{E0}	2011 capital returns endowment
e_r^{Tot}	2011 RMS projected value of exposed property
μ_r^S	2011 regional marginal propensity to save
$u_{r,s,g}^0$	2011 use of Argmington goods by sector
$k_{r,s}^0$	2011 capital use by sector
$l_{r,s}^0$	2011 labor use by sector
$o_{r,s}^{Y0}$	2011 output to local markets
$o_{r,s}^{N0}$	2011 output to domestic markets
$o_{r,s}^{F0}$	2011 output to foreign markets
$y_{r,s}^0$	2011 total output
$d_{r,g}^0$	2011 consumer goods demand

Calibration data

r^0	Reference growth rate
r^L	Reference labor productivity growth rate
$p_{r,a,y}$	Reference population projection
θ^x	Initial extant capital share
δ	Annual depreciation rate

Positive optimization variables:

Sector activity levels	
C_r	Consumption activity level index
$Y_{r,s}$	New production activity level index
$Y_{r,s}^X$	Extant production activity level index
$A_{r,s}$	Regional Argmington aggregate activity level index
G_r	Government activity level index
K	Extant capital exchange activity level index

Commodity prices

P^C_r	Consumption good price index
$P^A_{r,s}$	Armington aggregate good price index
$P^Y_{r,s}$	Local output good price index
P^N_s	Nationally traded good price index
P^F	International trade price index
P^G_r	Public sector output good price index
P^L_r	Regional wage rate index
R^N_r	Return index on new vintage capital
$R^X_{r,s}$	Return index on extant capital in production
R^E	Return index in extant capital exchange
P^S	Savings good price index

Consumer agent budget indices

R^A_r	Regional agent endowment index

Free optimization variables:

Auxiliary/constraint variables

I_r	Regional investment level
$\hat{I}_r$	Adjustment to investment endowments to balance savings price differences
$\hat{R^K}$	Realized rate of return after savings price adjustments
Θ^S_r	Regional share of national savings
$\theta^{RS}_{r,s}$	Share of regional investment by good

Non-optimization variables:

Growth variables

$k^{EX}_{r,y,y}$	Real extant capital earnings endowment
$k^{KN}_{r,s,y}$	Reference new capital use
$k^{KX}_{r,s,y}$	Reference extant capital use
$U^{LN}_{r,s,y}$	Labor used in new production
$U^{KN}_{r,s,y}$	Capital used in new production
γ^L_y	Labor productivity factor

Climate impact variables

$I^A_{r,y}$	Agricultural productivity climate factor (2011=1, $I^A_{r,y} > 1$ means yield increase)
θ^A_r	Share of RHG-MUSE agriculture made up of impacted crops (grains, oilseeds, cotton)
$I^L_{r,s,y}$	Labor productivity climate factor (2011=1, $I^L_{r,s,y} > 1$ means productivity increase)
$I^{In}_{r,y}$	RMS projection of inundation damages (2011=0, $I^{In}_{r,y} \geq 0$ by definition)
$I^{In'}_{r,y}$	Inundation damages, adjusted for previous property loss due to sea-level rise
$I^{St}_{r,y}$	RMS projection of storm damages (2011=0, $I^{St}_{r,y} \geq 0$ by definition)
$I^{St'}_{r,y}$	Storm damages, adjusted for property losses due to sea-level rise
$I^{BI}_{r,y}$	RMS projection of business interruption (2011=0, $I^{BI}_{r,y} \geq 0$ by definition)
$I^{BI'}_{r,y}$	Business interruption, adjusted for property losses due to sea-level rise
$I^E_{r,g,y}$	Energy expenditure climate factor (2011=1, $I^E_{r,g,y} > 1$ means exependiture increase)
$I^M_{r,a,y}$	Climate-related change in per-capita mortality rate (2011=0, $I^M_{r,a,y} > 0$ means rate increase)
$M_{r,a,y}$	Cumulative climate-related mortality change, with mortality by age advancing annually
$l^M_{r,y}$	Labor force, adjusted for climate-related mortality

4.3. Annual "static core" optimization module

The RHG-MUSE *static core* is written in the MPSGE modeling language, developed by Rutherford (1987) and documented in *MPSGE: A User's Guide* (2004). MPSGE models are characterized by collections of individually optimizing agents, both producers and consumers, interacting in a coherent general-equilibrium framework (see Section 4.3.5). Each agent consumes goods with a constant elasticity of substitution (CES) utility or consumption functions (for consumers and producers, respectively), and each producer converts its inputs into outputs with a constant elasticity of transformation (CET) production function. For the sake of brevity, we will describe the quantities and variables used to create the CES "nests" defining each agent's behavior, but will not provide the full set of equations defining RHG-MUSE. Böhringer and Wiegard (2003) provides a comprehensive overview of the equations governing the MCP equilibrium described by an MPSGE model.

The RHG-MUSE model core includes 1 aggregate consumer per region and 2 firms per region and sector (one for new vintage production and one for existing, or extant production). Government is represented by a single producer for each region. The consumer, whose budget is equal to the regional GDP (calculated by income, which is the sum of labor and capital earnings, tax revenue, net exports, and borrowing), divides its endowment in constant shares between consumption, savings, and government services. The producer receives the revenue from consumer, government, and investment spending and purchases labor, capital, and intermediate goods in order to produce regionally differentiated local products, national tradable products, or foreign exports. While additional details define the specific behavior of producers and consumers (described below), this dynamic forms the core relationship of the RHG-MUSE static core.

4.3.1. Production

Each sector produces three products, subject to a transformation nest allowing substitution between local, domestic, and international goods. Producers make use of intermediate inputs with zero substitution (i.e., any given sector cannot decide to change the mix of aggregated goods from which it makes its product) and factors. RHG-MUSE uses a putty-clay formulation that allows substitution of capital and labor in the first year of production but fixes their ratio in subsequent periods.

Figures D1 and D1 offer a graphical representation of this structure, showing the substitutability of capital and labor in new production in contrast with the fixed input shares of capital, labor, and intermediate goods in extant production.

4.3.2. Consumption

All income from the two factors of production — labor and capital — in each region accumulates to a representative consumer. In addition to the factor income, the consumers are endowed with the net foreign borrowing available each year due to the net trade imbalance. The consumers allocate this combined endowment into consumption by households and government and savings (figure D11). See section 4.3.4 for additional detail on the representation of trade.

4.3.3. Capital, savings, and investment

RHG-MUSE distinguishes between malleable and non-malleable capital. All extant capital stock is assumed to be non-malleable and is fixed to a particular region and sector, but new capital stock is mobile across regions and sectors.

Consumers have a constant marginal propensity to save, meaning they allocate a fixed portion of their income to saving (see figure D11). Investment generated through current-year savings is immediately transformed into new capital, driving an equalization of the rate of return across regions. The real value of savings is distributed as investment according to the distribution of investment expenditures across regions and sectors in the base-year SAM, but it is spent at a price equal to the regional price of investment goods, weighted by the regional distribution of new capital formation. This modification allows the model to capture changes in regional investment goods prices while maintaining the regional distribution of savings. This composite savings price is achieved through the use of four constraints.

Equation D1 sets the return on new capital, such that the returns paid to owners of stock in the national pool of new capital reflect changes in the price of investment goods in the regions and sectors in which new capital is being applied. The quantity $\sum_s \left[PA_{r,s}\theta^{RSAV}_{r,s}\right]$ is the regional average Armington good price weighted by the share of each good in the investment good bundle, determined by 2011 shares. Since all

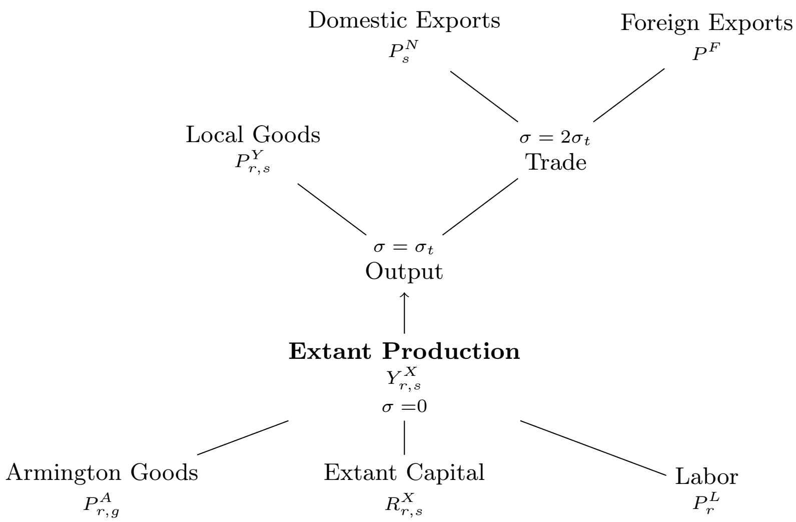


Figure D1: Extant production restricts the use of capital, labor, and intermediate goods to remain in fixed proportion. The relationship between capital and labor in extant production, which is fixed within each year, is updated every year with the new capital-labor mix as new production ages.

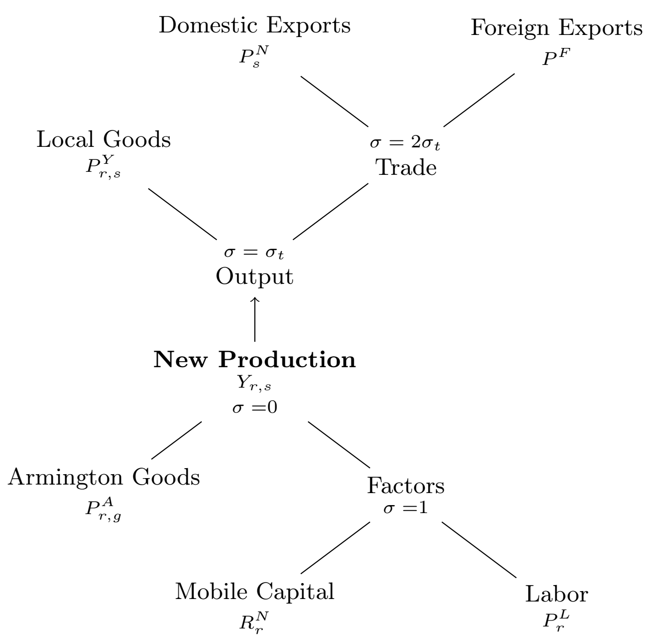


Figure D2: New production allows price-sensitive substitution of capital and labor, while maintaining the balance between factors and intermediate inputs seen in the social accounts.

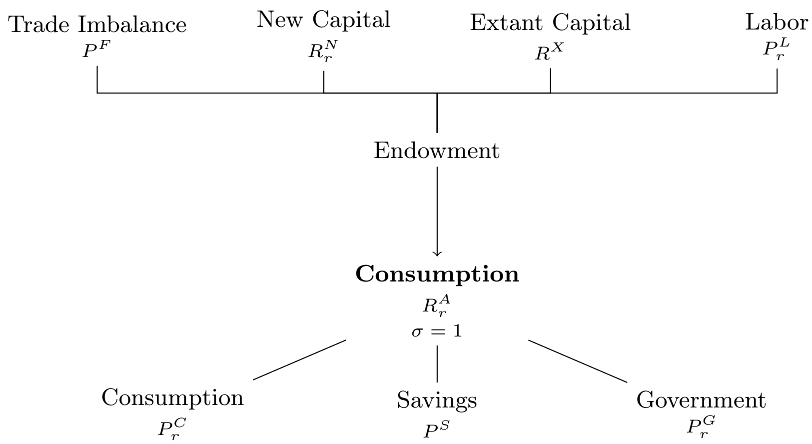


Figure D3: Regional demand is split between household consumption, savings, and government services. Endowments are the sum of labor and capital earnings (which are adjusted to include tax earnings), and regional borrowing. Note the variable sign of the trade imbalance quantities; negative endowments represent a forced expenditure rather than income.

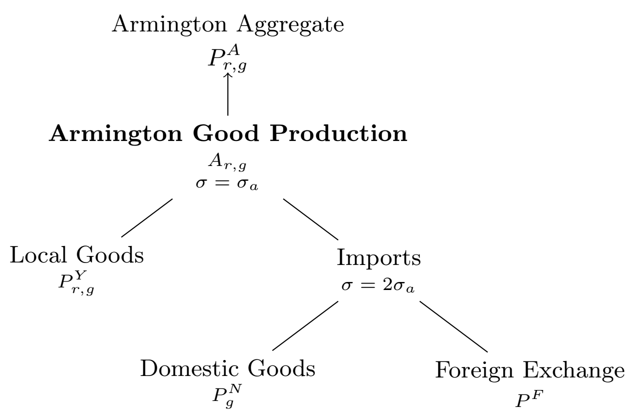


Figure D4: Armington trade assumes that imports are imperfect substitutes for local goods, and vice-versa. Similar to the transformation nests that allow producers to substitute local sales for exports, the Armington aggregate nest allows consumers of goods (all of which consume the Armington good $P_{r,s}^A$) to substitute between local and imported goods. Because these are treated as imperfect substitutes, a loss of productivity or utility will accrue to the producer or consumer, respectively, that substitutes away from their 2011 mix.

prices are indexed to 1 in 2011, this sets the effective return, $\hat{R^K}$, to be directly proportional to the rate of return in each region and inversely proportional to the change in the weighted average goods price in the regions and sectors where investments are made.

Equation D2 provides a similar function for the savings market, such that the price of savings PS is proportional to the regional average cost of investment goods weighted by the goods used in investment, $\sum_s \left[PA_{r,s}\theta_{r,s}^{RSAV}\right]$, averaged over all regions weighted by the regional distribution of investment, I_r.

Equation D3 assigns the value of Θ_r^S, an accounting variable that measures a region's share of national savings in a given year.

Finally, equation D4 makes a bookkeeping adjustment that balances the effects on regional GDP of having national savings and capital prices but local and sectoral differences in goods prices for investment or capital outlays, ensuring a closed economic system.

Capital earnings from new capital formation are returned to the owner of that capital through the savings price constraints and savings goods. This allows RHG-MUSE to track regional capital ownership separately from capital use as well as to allow changes in investment good prices in the region of capital use to affect returns in the region of ownership and to allocate returns accordingly. Earnings from extant capital are also distributed to the owner, but through an exchange market, such that ownership and use rates are

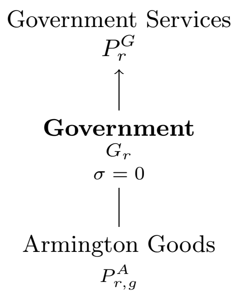


Figure D5: Government is modeled as a single regional producer that converts Armington aggregate goods into government services with a fixed efficiency based on 2011 government consumption estimates. The public services produced are a private good making up a fixed share of GDP.

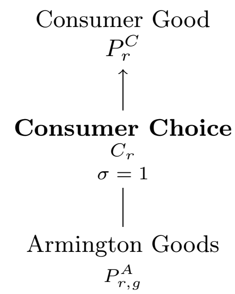
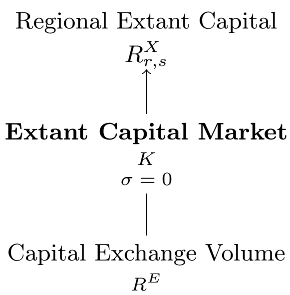


Figure D6: Real consumption is fixed as a share of regional GDP. Consumers have Cobb-Douglass utility functions, such that the share of consumption expenditures on any good is fixed to the 2011 consumption expenditure share.



$$\hat{R^K} \sum_{k\in s}\left[P^A_{i,k}\theta^{RS}_{i,k}\right] = R^N_i \qquad \forall\,(i\in r) \tag{D1}$$

$$\sum_{i\in r}\left[\sum_{k\in s}\left[P^A_{i,k}\theta^{RS}_{i,k}\right] I_i\right] = P^S \sum_{i\in r}[I_i] \tag{D2}$$

$$\Theta^S_i * \sum_{j\in r}\left[\mu^S_i * RA_i\right] = \mu^S_i * RA_i \qquad \forall\,(i\in r) \tag{D3}$$

$$\hat{I}_i P^S = r^0 \left[\Theta^S_i \sum_{j\in r}\left[R^N_j I_j\right] - R^N_i I_i\right] + I_i \sum_{k\in s}\left[P^A_{i,k}\theta^{RS}_{i,k} - P^S\right] \qquad \forall\,(i\in r) \tag{D4}$$

Figure D7: Savings, investment, and capital flows are governed by the behavior of a number of agents as well as by four constraints. Savings is a fixed share of regional GDP, and the money saved is distributed across regions as investment, which subsequently becomes new capital, such that the rate of return is equalized across regions. Existing capital held by regional agents is used in fixed quantities by region and sector. Allocations are determined by the usage of new capital in the year of investment, with a fixed proportion of capital depreciating each year, and returns are generated through a homogeneous stock market.

differentiated by region but rates of return equalize.

4.3.4. Trade

Commodities produced by the 9 sectors are modeled as nested Armington goods, in which local, domestic, and international goods are assumed to be imperfect substitutes for one another (Armington, 1969). Each region's international trade deficit is assumed to be fixed at base year (2011) nominal levels. All regional consumption of goods is a composite of local production, domestic trade from other regions and foreign goods (see figure D4) and all regional production is output to a mix of local, domestic, and international markets (see figures D1 and D2).

Net foreign borrowing is fixed nominally in RHG-MUSE, meaning that as the economy grows the deficit will shrink as a share of GDP. This is consistent with the representation of national deficits in many recursive-dynamic CGE models, and satisfies the theoretical principle that a large deficit is unsustainable in the long run. However, the United States, in addition to many other countries, has maintained a deficit representing a relatively stable share of GDP over multiple decades. This would indicate that modeling net foreign borrowing as a constant share of GDP might be more realistic. In the version of RHG-MUSE used in the *American Climate Prospectus* we chose to use the former; that is, to fix regional borrowing at 2011 nominal levels regardless of GDP changes for two reasons. Firstly, RHG-MUSE is not forward-looking, and currently there is no penalty for increased borrowing; therefore, representing foreign borrowing as a fixed share of GDP enables an unrealistic positive feedback to borrowing. Secondly, when the foreign borrowing rate is fixed to GDP, damages to GDP from climate change (or elsewhere) are magnified through reduced borrowing. This may have a realistic interpretation, as global damages from climate change could tighten international lending markets, leading to a reduction in US borrowing from the counter-factual "no-impact" baseline. This effect is, however, highly uncertain and we have chosen to model fixed nominal borrowing as a more conservative estimate of macroeconomic damages. We encourage further research in this area so that future work may attempt to quantify the impact of climate damages on currency and lending markets.

4.3.5. Yearly static core optimization

Every year, the *static core's* calibration data is updated using the *updating equations* (described in section 4.4) and is then resolved for the state of the economy and any impacts occurring in that year. This recursive-dynamic framework mimics an agent behaving optimally for current conditions but not preparing for events occurring in future model periods directly. Forward-looking behavior is simulated, to the extent that it exists today, in the preferences expressed in the current IMPLAN data. For example, while savings would be an irrational behavior in a purely myopic world, agents in RHG-MUSE do exhibit a constant marginal propensity to save, as current regional savings rates are preserved throughout the model horizon.

While the *updating equations* are a set of assignment statements using data from one year to determine values in the next, the *static core* is an optimization problem in which each region's representative agent maximizes its own utility subject to a budget of endowed goods (in RHG-MUSE, this budget stems from labor earnings, returns on owned capital, and foreign borrowing). Mathematically, the single-year optimization problem takes the form of a "mixed complementarity problem" (MCP), which is defined by a set of inequalities that, when solved, provide by definition the solution to the set of optimization problems for all regions simultaneously. The preferences and technologies in the RHG-MUSE *static core* are expressed through nested CES utility/consumption functions and CET production functions which are related by three fundamental equilibrium conditions:

- Zero profit condition
  Producers must have zero economic profits after all payments to intermediate producers, owners of factors such as capital and labor, outlays for investment and savings, and any other expenses. In effect, this constraint means that producers cannot waste revenue.

- Market clearance condition
  The total endowment by consumers plus the total production by producers of all goods and services must equal the total consumption of each good by both consumers and producers. In effect, this constraint means that all goods must have an equal number of sources and sinks.

- Consumer budget condition
  Consumers may not spend more than that with which they are endowed. Endowments may include labor income, capital earnings, and borrowing, and expenditures include private and government consumption and savings. In effect, this constraint means that consumers cannot spend money to which they do not have access.

In RHG-MUSE, we make no theoretical exceptions to the above statements in the form of imperfect competition or inter-temporal constraints. We do however, allow some markets to have demand fall short of supply. In this case, the price for the associated good will be zero, and the market will still clear.

It is important to note that this is not a single agent model. Single agent models are frequently employed in energy and climate policy analysis in order to determine a utility-maximizing policy for the entire country or planet. Such models have a single objective function that optimizes utility for the entire system. For example, the Nordhaus (1994) models DICE and RICE use population-weighted discounted utility of regional per-capita consumption. Measures are usually taken to ensure that inequality is not too greatly exacerbated (the DICE/RICE maximand employs a diminishing marginal utility of consumption), but in principle increases in inequality could be found to be "optimal" if the net global utility payoff were positive, regardless of the distributional consequences.

Instead, the optimization carried out in the RHG-MUSE *static core* is structured such that each of the regional consumer and producer agents are *individually optimizing.* This is a property of the MCP equilibrium employed by the MPSGE language — the solution to the set of conditions detailed in the model by definition maximizes the utility of each agent described in the nests in sections 4.3.1 to 4.3.4. Therefore, any increases in inequality observed in the model outputs may only have come from changes in the calibrating data (e.g. population, capital ownership rates), from economic forces beyond the agent's control (prices) or from climate impacts, and the optimal solution each year will be at least as good for each agent, known as a Pareto improvement, relative to the initial conditions before the optimization took place.

Of course, while RHG-MUSE in its current form does enable the examination of changes in inter-regional inequality, it cannot be used to study changes in intra-regional inequality, such as differential impacts on various income or age groups. This topic is explored conceptually in Chapter 15, and further study in this area would be useful in elucidating the distributional consequences that impacts from climate change may have.

4.4. RHG-MUSE dynamics

The static core of RHG-MUSE is based on 2011 data and could be run as a single year model. If climate impacts were to be applied directly to the static core, this would enable a "comparative statics" study, in which the economy of 2011 is tested in a counterfactual climate setting. The dynamic *updating equations* presented in this section modify the base data each year as a function of the outputs of the previous year's optimization as well as a small number of external inputs. This structure defines a no-impact "baseline," to which climate change scenarios are compared. Note that the baseline scenario is not truly without the influence of climate, but simply with the same influence that the climate had on the economy in 2011.

4.4.1. Population growth and the labor supply

The population in each region is assumed to grow at the United States average growth rate as projected by the United Nations (UN Population Division, 2012; Raftery and Heilig., 2012). Age cohorts maintain their share of the state population, and the change in the labor supply is equal to the change in the number of people between the ages of 15 and 64, inclusive. Migration of labor between regions is not allowed. This population model was used not because of its likelihood but because it preserves the regional and sectoral balance used to calibrate the model, enabling a faithful comparison to the economy of today. In reality, the population will likely shift toward urban centers and coastal areas. Migration will likely also play a role in the way that Americans respond to climate change, but the empirical work quantifying these changes was deemed not yet sufficient to be relied on by this report; furthermore, costs associated with large-scale migration are even more difficult to quantify. It is unclear whether the adaptive benefit from increased domestic and international migration would be larger than the increased costs.

4.4.2. Capital stock model

Capital stock changes are driven by a vintaged capital growth model. In 2011, the earnings from extant capital equal the IMPLAN capital earnings times the initial extant capital share, θ^X. In subsequent years, the endowment of earnings from the extant capital exchange (in real terms), k_r^{EX}, equals the value of investment in that year, plus the remaining earnings from the year before, depreciated by the annual depreciation rate δ. Each year, y, the existing capital stock and new capital stock use in each sector and region is depreciated and becomes the extant capital stock for that sector and region for the next year. Each region's share of national earnings from new capital stock are returned to the regional agents according to their share of national investment, Θ_r^S:

$$k_{i,t}^{EX} = \begin{cases} k_i^{E0}\theta^X & t = 2011 \\ (1-\delta)(k_{i,t}^{EX} + \Theta_i^S \sum_{j\in r}\left[\sum_{k\in s}\left[U_{j,k}^{KN}\right]\right] & t > 2011 \end{cases} \quad \forall\, i \in r, t \in y \tag{D5}$$

Each year, after the *static core* optimization, capital endowments are updated to equal the total previous year's capital stock, depreciated by the annual depreciation rate δ.

Capital and labor cannot be substituted for one another in the extant production block (see section 4.3.1), but the ratio of their use in that block is updated over time. In 2011, the ratio of capital to labor in each region and sector is determined by the 2011 IMPLAN data. In subsequent periods, the optimal capital to labor ratio used in the new production block updates this ratio in proportion to the relative size of the new and extant capital stocks:

$$l_{i,k,t}^{X} = \frac{l_{i,k,t-1}^{X} * Y_{i,k,t-1}^{X} + \gamma^{L} U_{r,s}^{LN}}{Y_{r,s}^{X} + Y_{r,s}^{N}} \quad \forall\, i \in r, k \in s, t \in y \tag{D6}$$

$$k_{i,k,t}^{X} = \frac{k_{i,k,t-1}^{X} * Y_{i,k,t-1}^{X} + U_{r,s}^{KN}}{Y_{r,s}^{X} + Y_{r,s}^{N}} \quad \forall\, i \in r, k \in s, t \in y \tag{D7}$$

4.4.3. Technological change and economic adaptation

Productivity changes through annual increases in labor productivity:

$$\gamma_{t}^{L} = \begin{cases} 1 & y = 2011 \\ \left(1 + r^{L}\right) \gamma_{t-1}^{L} & y > 2011 \end{cases} \quad \forall\, t \in y \tag{D8}$$

Changes in technology are applied to the production block as a decrease in the labor required to produce a given amount of output. To account for the rebound effect, the inverse of the productivity change is applied to the initial observed labor price for the new producer (reference prices have no effect for Leontief producers in MPSGE). Both of these then influence the production possibility curve, and thus the optimal behavior, of the producer in the optimization (see figure D8).

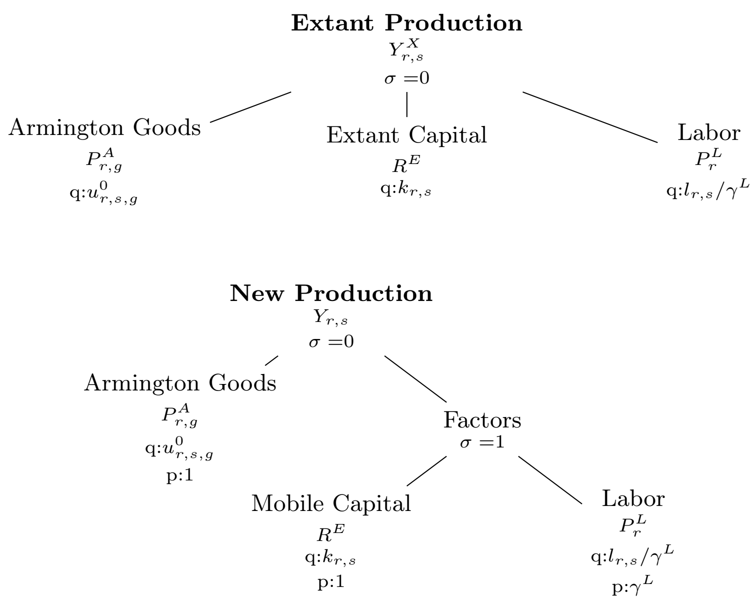


Figure D8: The labor-capital share used in new production each year updates extant production in the next year according to the relative size of each sector. This mechanism captures both exogenous technology change (labor productivity growth) and endogenous economic adaptation (labor-capital rebalancing). q: values signify the index used to scale the variable's quantity; p: values give the reference price used to scale the price observed by that producer.

4.5. Integrating climate impacts in RHG-MUSE

Of the impacts quantified in the macroeconomic model, agriculture, labor, and energy costs and benefits as well as coastal storm-related business interruption are applied directly to the *static core*. Mortality and sea-level related coastal damages affect the stocks of labor and capital, respectively, and are applied in the *updating equations*.

4.5.1. Agriculture

Changes in agricultural productivity are implemented through changes in output productivity of the agriculture sector. Specifically, the reference quantity produced is changed by the agricultural productivity impact I_{r}^{A} times the regional share of the agriculture sector made up by maize, wheat, oilseeds, and cotton, θ_{r}^{A}, and the rebound effect is accounted for through inverse changes in the observed producer price (see figure D9).

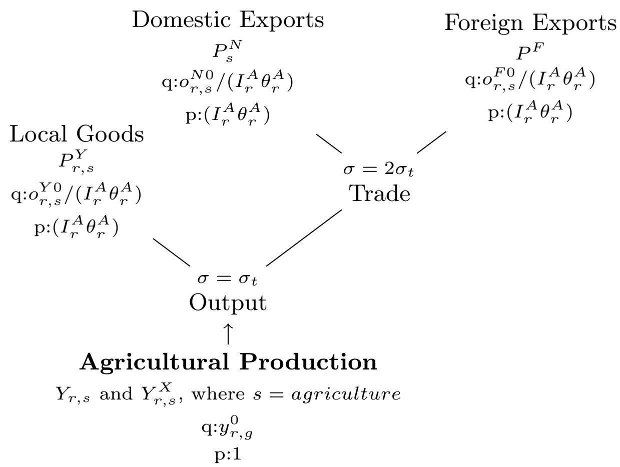


Figure D9: Agricultural productivity impacts affect both new and extant production identically. Sector output may be sold in local, domestic, and foreign exchange markets, and the productivity of this transformation nest is moderated by the agricultural productivity factor I^A_r times the share of total agriculture made up by impacted sectors, θ^A_r. The rebound effect is accounted for by inverse changes in price. q: values signify the index used to scale the variable's quantity; p: values give the reference price used to scale the price observed by that producer.

4.5.2. Labor

Labor productivity impacts are implemented as temporary reductions in labor productivity. The sectors affected by high- and low-risk labor impacts are given in table D11. The "risk" of an industry corresponds to the portion of the industry's labor that is exposed to outdoor temperatures. The econometric impact functions described in Technical Appendix II have the same two-tiered structure, developed using data from comparable sector structures. The mechanism for affecting labor productivity is identical to that used in baseline labor productivity growth, and accounts for the rebound effect in the same way (see section 4.4.3), such that the final (climate-impacted) labor productivity $\gamma^{L'}_{r,s}$ is defined:

$$\gamma^{L'}_{i,k} = \gamma^L I^L_{i,k} \quad \forall i \in r, k \in s \tag{D9}$$

where the impact $I^L_{r,s}$ is the climate impact for the risk category corresponding to that sector.

Table D11: High- and low-risk labor productivity impact sectors. Labor productivity impacts affects only the efficiency of labor use by these sectors, so more capital intensive industries, such as agriculture and real estate, are less vulnerable than labor-intensive industries, such as indoor and outdoor services.

High Risk	**Low Risk**
Agriculture	Indoor Services
Transportation	Real Estate
Outdoor Services	
Infrastructure	
Manufacturing	
Mining	
Energy	

4.5.3. Energy

Changes in energy demand are effectively a change in the ability to profitably make use of energy (such as for heat in industrial processes or lighting in commercial buildings) or to derive utility from energy (such as in home heating). Consumers and businesses may substitute other goods for energy, but at some cost. As a result, in RHG-MUSE, changes in energy expenditures are implemented similarly to changes in labor productivity — they affect the ability of producers to create output or consumers to derive utility from a given amount of energy goods. Because demands for intermediate goods for producers are Leontief (CES functions with an elasticity of 0), the index price is irrelevant in MPSGE; however, the rebound in consumer purchases is accounted for by an inverse change in prices (see figure D10).

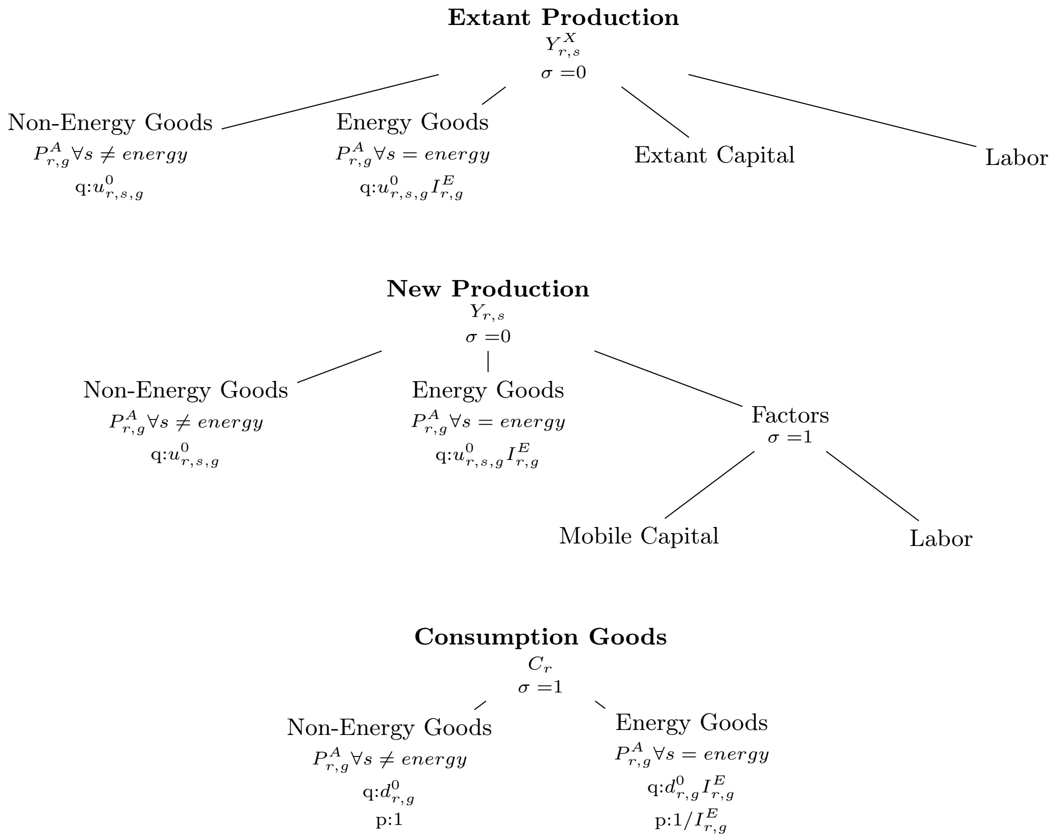


Figure D10: Energy. q: values signify the index used to scale the variable's quantity; p: values give the reference price used to scale the price observed by that producer.

4.5.4. Coastal impacts

The RMS North Atlantic Hurricane Model (see Technical Appendix III) simulates damages that would occur due to sea level rise and the hurricane patterns for each year and scenario given current property values. It is not a multi-year simulation. To avoid over-counting damages, we make two assumptions: firstly, in any given scenario, inundation damages are incremental, determined by the difference between projected inundation damages in the current year and the maximum previous inundation:

$$I^{In'}_{i,t} = \begin{cases} 0 & t = 2011 \\ \max\left\{I^{In}_{i,t} - \max\left\{I^{In}_{i,2011}, \ldots, I^{In}_{i,t-1}\right\}, 0\right\} & t > 2011 \end{cases} \qquad \forall\, t \in y \tag{D10}$$

Secondly, we assume that property and business activity already inundated can no longer be damaged by coastal storms, effectively assuming that reinvestment in the region takes place away from the coast. Furthermore, we do not permanently reduce the productivity of reinvestments. This is conservative - historically large shares of damaged property is rebuilt in areas still exposed to coastal storm damage; additionally, many businesses and investments rely on proximity to coastlines and would incur costs or lose value if moved inland. We accomplish this reduction in storm damages, $I^{St'}_{r,y}$, and business interruption, $I^{BI'}_{r,y}$, by decreasing the value of exposed property, e_r^{Tot} by the share of total state property that has been inundated:

$$I_{i,t}^{St'} = \left[1 - \frac{I_{i,t}^{In'}}{e_i^{Tot}}\right] I_{i,t}^{St} \quad \forall\, i \in r, t \in y \tag{D11}$$

$$I_{i,t}^{BI'} = \left[1 - \frac{I_{i,t}^{In'}}{e_i^{Tot}}\right] I_{i,t}^{BI} \quad \forall\, i \in r, t \in y \tag{D12}$$

Unlike agriculture, labor, and energy impacts, which solely affect the *static core* of RHG-MUSE, coastal impacts have an effect both on the *static core* and on the *updating equations*. Property lost due to local sea level (LSL) rise-driven inundation and damage due to tropical storms and Nor'easters affect the capital stock directly, while business interruption during and immediately following storms affects output productivity.

The mechanism for damaging output is identical to that used in agricultural impacts, with the exception that business interruption affects all sectors equally (see figure D9). When a portion of the business activity is reduced in a given year and region, the total output productivity for all sectors in that region is reduced, regardless of the destination market. This will change the balance of trade in the region, as local consumers demand more imported goods to replace the lost local output; similar compensating changes will also occur in other regions as they substitute away from goods imported from the damaged region. However, this effect will be offset somewhat by the rise in operating expenses for local firms and the resulting "rebound," which will drive a reduction in demand.

Capital damage from inundation and storms is represented as a premature depreciation of extant capital, occurring at the end of the year in which the damage occurs.

$$k_{i,t}^{EX} = \begin{cases} k_i^{E0}\theta^X & t = 2011 \\ (1-\delta)(k_{i,t-1}^{EX} + \Theta_i^S \sum_{j\in r}\left[\sum_{k\in s}\left[U_{j,k}^{KN}\right]\right] & t > 2011 \end{cases} \quad \forall\, i \in r, t \in y \tag{D13}$$

4.5.5. Mortality

Unlike the direct cost and benefit calculations described in section 2.3, which apply changes in the mortality rate to the current population, RHG-MUSE uses a population model to track mortality through time. The baseline projection is described in section 4.4.1. Changes in mortality (in persons, by age) accumulate over time, age every year, and are subtracted from the base population each year. The change in the labor force is calculated as the change in the 15 to 64 population.

$$M_{i,q,t} = \begin{cases} 0 & t = 2011 \\ M_{i,q-1,t} + (p_{i,q,t} - M_{i,q-1,t}) * (I_{i,q,t}^M) & t > 2011 \end{cases} \quad \forall\, i \in r, q \in a, t \in y \tag{D14}$$

$$l_{i,t}^M = l_{i,t}^0 \left[\frac{\sum_{q\in a} p_{i,q,t} - M_{i,q,t}}{\sum_{q\in a} p_{i,q,t}}\right] \tag{D15}$$

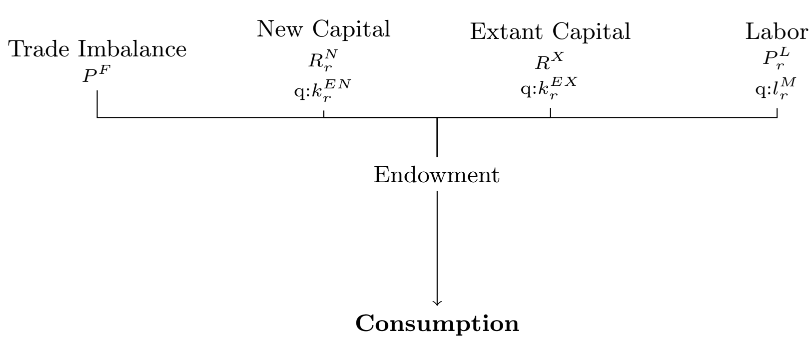


Figure D11: Consumption. q: values signify the index used to scale the variable's quantity; p: values give the reference price used to scale the price observed by that producer.

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5. Supplemental Tables

Table D12: Data used in extrapolating from "physical impact" bins to single years of age used in CGE model

Physical Impact	Age Cohort	Cohort Deaths	Cohort Population
0 to 1	0 to 1	332,697	47,830,261
1 to 44	1 to 4	57,529	189,286,073
	5 to 9	34,262	239,385,956
	10 to 14	44,258	250,939,740
	15 to 19	157,564	255,076,636
	20 to 24	231,954	246,218,551
	25 to 34	501,208	477,763,701
	35 to 44	1,005,193	522,168,558
45 to 64	45 to 54	2,118,807	500,140,370
	55 to 64	3,258,625	358,921,022
65 +	65 to 74	4,948,370	231,986,715
	75 to 84	8,109,495	154,248,308
	85 +	8,372,695	56,742,313

Table D13: Sectoral aggregation scheme used in the CGE model

Sector	**IMPLAN code**	**IMPLAN name**
Agriculture	1	Oilseed farming
	2	Grain farming
	8	Cotton farming
	3	Vegetable and melon farming
	4	Fruit farming
	5	Tree nut farming
	6	Greenhouse nursery and floriculture production
	7	Tobacco farming
	9	Sugarcane and sugar beet farming
	10	All other crop farming (except algae seaweed and other plant aquaculture)
	15	Forest nurseries forest products and timber tracts
	16	Logging
	11	Cattle ranching and farming
	12	Dairy cattle and milk production
	13	Poultry and egg production
	14	Animal production except cattle and poultry and eggs (algae seaweed and other plant aquaculture)
	17	Fishing
	18	Hunting and trapping
	19	Support activities for agriculture and forestry
Energy	32	Natural gas distribution
	115	Petroleum refineries
	119	All other petroleum and coal products manufacturing
	31	Electric power generation transmission and distribution
	428	Federal electric utilities
	431	State and local government electric utilities
Infrastructure	33	Water sewage and other systems
	390	Waste management and remediation services
	351	Telecommunications (broadband ISP; telephone ISP)
Transportation	332	Air transportation
	333	Rail transportation
	334	Water transportation
	335	Truck transportation
	336	Transit and ground passenger Transportation
	337	Pipeline transportation
	338	Scenic and sightseeing transportation and support activities for transportation
	430	State and local government passenger transit
Mining	20	Oil and gas extraction
	28	Drilling oil and gas wells
	29	Support activities for oil and gas operations
	21	Coal mining
	22	Iron ore mining
	23	Copper nickel lead and zinc mining
	24	Gold silver and other metal ore mining
	25	Stone mining and quarrying
	26	Sand gravel clay and ceramic and refractory minerals mining and quarrying
	27	Other nonmetallic mineral mining and quarrying

	30	Support activities for other mining
Manufacturing	41	Dog and cat food manufacturing
	42	Other animal food manufacturing
	43	Flour milling and malt manufacturing
	44	Wet corn milling
	45	Soybean and other oilseed processing
	46	Fats and oils refining and blending
	47	Breakfast cereal manufacturing
	48	Sugar cane mills and refining
	49	Beet sugar manufacturing
	50	Chocolate and confectionery manufacturing from cacao beans
	51	Confectionery manufacturing from purchased chocolate
	52	Nonchocolate confectionery manufacturing
	53	Frozen food manufacturing
	54	Fruit and vegetable canning pickling and drying
	55	Fluid milk and butter manufacturing
	56	Cheese manufacturing
	57	Dry condensed and evaporated dairy product manufacturing
	58	Ice cream and frozen dessert manufacturing
	59	Animal (except poultry) slaughtering rendering and processing
	60	Poultry processing
	61	Seafood product preparation and packaging
	62	Bread and bakery product manufacturing
	63	Cookie cracker and pasta manufacturing
	64	Tortilla manufacturing
	65	Snack food manufacturing
	66	Coffee and tea manufacturing
	67	Flavoring syrup and concentrate manufacturing
	68	Seasoning and dressing manufacturing
	69	All other food manufacturing
	70	Soft drink and ice manufacturing
	71	Breweries
	72	Wineries
	73	Distilleries
	74	Tobacco product manufacturing
	75	Fiber yarn and thread mills
	76	Broadwoven fabric mills
	77	Narrow fabric mills and schiffli machine embroidery
	78	Nonwoven fabric mills
	79	Knit fabric mills
	80	Textile and fabric finishing mills
	81	Fabric coating mills
	82	Carpet and rug mills
	83	Curtain and linen mills
	84	Textile bag and canvas mills
	85	All other textile product mills (empbroidery contractors)
	86	Apparel knitting mills
	87	Cut and sew apparel contractors (exc. embroidery contractors)
	88	Mens and boys cut and sew apparel manufacturing
	89	Womens and girls cut and sew apparel manufacturing
	90	Other cut and sew apparel manufacturing
	91	Apparel accessories and other apparel manufacturing
	92	Leather and hide tanning and finishing
	93	Footwear manufacturing

94	Other leather and allied product manufacturing
95	Sawmills and wood preservation
96	Veneer and plywood manufacturing
97	Engineered wood member and truss manufacturing
98	Reconstituted wood product manufacturing
99	Wood windows and doors and millwork
100	Wood container and pallet manufacturing
101	Manufactured home (mobile home) manufacturing
102	Prefabricated wood building manufacturing
103	All other miscellaneous wood product manufacturing
104	Pulp mills
105	Paper mills
106	Paperboard Mills
107	Paperboard container manufacturing
108	Coated and laminated paper packaging paper and plastics film manufacturing
109	All other paper bag and coated and treated paper manufacturing
110	Stationery product manufacturing
111	Sanitary paper product manufacturing
112	All other converted paper product manufacturing
113	Printing
114	Support activities for printing
116	Asphalt paving mixture and block manufacturing
117	Asphalt shingle and coating materials manufacturing
118	Petroleum lubricating oil and grease manufacturing
120	Petrochemical manufacturing
121	Industrial gas manufacturing
122	Synthetic dye and pigment manufacturing
123	Alkalies and chlorine manufacturing
124	Carbon black manufacturing
125	All other basic inorganic chemical manufacturing
126	Other basic organic chemical manufacturing
127	Plastics material and resin manufacturing
128	Synthetic rubber manufacturing
129	Artificial and synthetic fibers and filaments manufacturing
130	Fertilizer manufacturing
131	Pesticide and other agricultural chemical manufacturing
132	Medicinal and botanical manufacturing
133	Pharmaceutical preparation manufacturing
134	In-vitro diagnostic substance manufacturing
135	Biological product (except diagnostic) manufacturing
136	Paint and coating manufacturing
137	Adhesive manufacturing
138	Soap and cleaning compound manufacturing
139	Toilet preparation manufacturing
140	Printing ink manufacturing
141	All other chemical product and preparation manufacturing
142	Plastics packaging materials and unlaminated film and sheet manufacturing
143	Unlaminated plastics profile shape manufacturing
144	Plastics pipe and pipe fitting manufacturing
145	Laminated plastics plate sheet (except packaging) and shape manufacturing
146	Polystyrene foam product manufacturing

147	Urethane and other foam product (except polystyrene) manufacturing
148	Plastics bottle manufacturing
149	Other plastics product manufacturing (exc. Inflatable plastic boats)
150	Tire manufacturing
151	Rubber and plastics hoses and belting manufacturing
152	Other rubber product manufacturing (exc. Inflatable rubber boats)
153	Pottery ceramics and plumbing fixture manufacturing
154	Brick tile and other structural clay product manufacturing
155	Clay and nonclay refractory manufacturing
156	Flat glass manufacturing
157	Other pressed and blown glass and glassware manufacturing
158	Glass container manufacturing
159	Glass product manufacturing made of purchased glass
160	Cement manufacturing
161	Ready-mix concrete manufacturing
162	Concrete pipe brick and block manufacturing
163	Other concrete product manufacturing
164	Lime and gypsum product manufacturing
165	Abrasive product manufacturing
166	Cut stone and stone product manufacturing
167	Ground or treated mineral and earth manufacturing
168	Mineral wool manufacturing
169	Miscellaneous nonmetallic mineral products
170	Iron and steel mills and ferroalloy manufacturing
171	Steel product manufacturing from purchased steel
172	Alumina refining and primary aluminum production
173	Secondary smelting and alloying of aluminum
174	Aluminum product manufacturing from purchased aluminum
175	Primary smelting and refining of copper
176	Primary smelting and refining of nonferrous metal (except copper and aluminum)
177	Copper rolling drawing extruding and alloying
178	Nonferrous metal (except copper and aluminum) rolling drawing extruding and alloying
179	Ferrous metal foundries
180	Nonferrous metal foundries
181	All other forging stamping and sintering
182	Custom roll forming
183	Crown and closure manufacturing and metal stamping
184	Cutlery utensil pot and pan manufacturing
185	Handtool manufacturing
186	Plate work and fabricated structural product manufacturing
187	Ornamental and architectural metal products manufacturing
188	Power boiler and heat exchanger manufacturing
189	Metal tank (heavy gauge) manufacturing
190	Metal can box and other metal container (light gauge) manufacturing
191	Ammunition manufacturing
192	Arms ordnance and accessories manufacturing
193	Hardware manufacturing
194	Spring and wire product manufacturing
195	Machine shops
196	Turned product and screw nut and bolt manufacturing
197	Coating engraving heat treating and allied activities
198	Valve and fittings other than plumbing

199	Plumbing fixture fitting and trim manufacturing
200	Ball and roller bearing manufacturing
201	Fabricated pipe and pipe fitting manufacturing
202	Other fabricated metal manufacturing
203	Farm machinery and equipment manufacturing
204	Lawn and garden equipment manufacturing
205	Construction machinery manufacturing
206	Mining and oil and gas field machinery manufacturing
214	Air purification and ventilation equipment manufacturing
215	Heating equipment (except warm air furnaces) manufacturing
216	Air conditioning refrigeration and warm air heating equipment manufacturing (laboratory freezers)
207	Other industrial machinery manufacturing (laboratory distilling equipment)
208	Plastics and rubber industry machinery manufacturing
209	Semiconductor machinery manufacturing
210	Vending commercial industrial and office machinery manufacturing
211	Optical instrument and lens manufacturing
212	Photographic and photocopying equipment manufacturing
213	Other commercial and service industry machinery manufacturing
217	Industrial mold manufacturing
218	Metal cutting and forming machine tool manufacturing
219	Special tool die jig and fixture manufacturing
220	Cutting tool and machine tool accessory manufacturing
221	Rolling mill and other metalworking machinery manufacturing
222	Turbine and turbine generator set units manufacturing
223	Speed changer industrial high-speed drive and gear manufacturing
224	Mechanical power transmission equipment manufacturing
225	Other engine equipment manufacturing
226	Pump and pumping equipment manufacturing
227	Air and gas compressor manufacturing
228	Material handling equipment manufacturing
229	Power-driven handtool manufacturing
230	Other general purpose machinery manufacturing (laboratory scales and balances laboratory centrifuges)
231	Packaging machinery manufacturing
232	Industrial process furnace and oven manufacturing (laboratory furnaces and ovens)
233	Fluid power process machinery
234	Electronic computer manufacturing
235	Computer storage device manufacturing
236	Computer terminals and other computer peripheral equipment manufacturing
237	Telephone apparatus manufacturing
238	Broadcast and wireless communications equipment
239	Other communications equipment manufacturing
240	Audio and video equipment manufacturing
241	Electron tube manufacturing
242	Bare printed circuit board manufacturing
243	Semiconductor and related device manufacturing
244	Electronic capacitor resistor coil transformer and other inductor manufacturing
245	Electronic connector manufacturing
246	Printed circuit assembly (electronic assembly) manufacturing

247	Other electronic component manufacturing
248	Electromedical and electrotherapeutic apparatus manufacturing
249	Search detection and navigation instruments manufacturing
250	Automatic environmental control manufacturing
251	Industrial process variable instruments manufacturing
252	Totalizing fluid meters and counting devices manufacturing
253	Electricity and signal testing instruments manufacturing
254	Analytical laboratory instrument manufacturing
255	Irradiation apparatus manufacturing
256	Watch clock and other measuring and controlling device manufacturing
257	Software audio and video media reproducing
258	Magnetic and optical recording media manufacturing
259	Electric lamp bulb and part manufacturing
260	Lighting fixture manufacturing
261	Small electrical appliance manufacturing
262	Household cooking appliance manufacturing
263	Household refrigerator and home freezer manufacturing
264	Household laundry equipment manufacturing
265	Other major household appliance manufacturing
266	Power distribution and specialty transformer manufacturing
267	Motor and generator manufacturing
268	Switchgear and switchboard apparatus manufacturing
269	Relay and industrial control manufacturing
270	Storage battery manufacturing
271	Primary battery manufacturing
272	Communication and energy wire and cable manufacturing
273	Wiring device manufacturing
274	Carbon and graphite product manufacturing
275	All other miscellaneous electrical equipment and component manufacturing
276	Automobile manufacturing
277	Light truck and utility vehicle manufacturing
278	Heavy duty truck manufacturing
279	Motor vehicle body manufacturing
280	Truck trailer manufacturing
281	Motor home manufacturing
282	Travel trailer and camper manufacturing
283	Motor vehicle parts manufacturing
284	Aircraft manufacturing
285	Aircraft engine and engine parts manufacturing
286	Other aircraft parts and auxiliary equipment manufacturing
287	Guided missile and space vehicle manufacturing
288	Propulsion units and parts for space vehicles and guided missiles
289	Railroad rolling stock manufacturing
290	Ship building and repairing
291	Boat building
292	Motorcycle bicycle and parts manufacturing
293	Military armored vehicle tank and tank component manufacturing
294	All other transportation equipment manufacturing
295	Wood kitchen cabinet and countertop manufacturing
296	Upholstered household furniture manufacturing
297	Nonupholstered wood household furniture manufacturing
298	Metal and other household furniture manufacturing
299	Institutional furniture manufacturing

	300	Office furniture manufacturing
	301	Custom architectural woodwork and millwork manufacturing
	302	Showcase partition shelving and locker manufacturing
	303	Mattress manufacturing
	304	Blind and shade manufacturing
	305	Surgical and medical instrument manufacturing
	306	Surgical appliance and supplies manufacturing
	307	Dental equipment and supplies manufacturing
	308	Ophthalmic goods manufacturing
	309	Dental laboratories
	310	Jewelry and silverware manufacturing
	311	Sporting and athletic goods manufacturing
	312	Doll toy and game manufacturing
	313	Office supplies (except paper) manufacturing
	314	Sign manufacturing
	315	Gasket packing and sealing device manufacturing
	316	Musical instrument manufacturing
	317	All other miscellaneous manufacturing
	318	Broom brush and mop manufacturing
Outdoor Services	34	Construction of new nonresidential commercial and health care structures
	35	Construction of new nonresidential manufacturing structures
	36	Construction of other new nonresidential structures
	37	Construction of new residential permanent site single- and multi-family structures
	38	Construction of other new residential structures
	39	Maintenance and repair construction of nonresidential maintenance and repair
	40	Maintenance and repair construction of residential structures
Real Estate	360	Real estate
	361	Imputed rental value for owner-occupied dwellings
Indoor Services	394	Offices of physicians dentists and other health practitioners
	395	Home health care services
	396	Medical and diagnostic labs and outpatient and other ambulatory care services
	397	Hospitals
	398	Nursing and residential care facilities
	399	Child day care services
	400	Individual and family services
	401	Community food housing and other relief services including rehabilitation services
	319	Wholesale trade
	320	Retail - Motor vehicle and parts
	321	Retail - Furniture and home furnishings
	322	Retail - Electronics and appliances
	323	Retail - Building material and garden supply
	324	Retail - Food and beverage
	325	Retail - Health and personal care
	326	Retail - Gasoline stations
	327	Retail - Clothing and clothing accessories
	328	Retail - Sporting goods hobby book and music
	329	Retail - General merchandise
	330	Retail - Miscellaneous
	331	Retail - Nonstore

362	Automotive equipment rental and leasing
363	General and consumer goods rental except video tapes and discs
364	Video tape and disc rental
378	Photographic services
379	Veterinary services
365	Commercial and industrial machinery and equipment rental and leasing
366	Lessors of nonfinancial intangible assets
339	Couriers and messengers
340	Warehousing and storage
341	Newspaper publishers
342	Periodical publishers
343	Book publishers
344	Directory mailing list and other publishers
345	Software publishers
346	Motion picture and video industries
347	Sound recording industries
348	Radio and television broadcasting
349	Cable and other subscription programming
350	Internet publishing and broadcasting
352	Data processing hosting and related services
353	Other information services
354	Monetary authorities and depository credit intermediation
355	Nondepository credit intermediation and related activities
356	Securities commodity contracts investments and related activities
357	Insurance carriers
358	Insurance agencies brokerages and related activities
359	Funds trusts and other financial vehicles
367	Legal services
368	Accounting tax preparation bookkeeping and payroll services
369	Architectural engineering and related services
370	Specialized design services
371	Custom computer programming services
372	Computer systems design services
373	Other computer related services including facilities management
374	Management scientific and technical consulting services
375	Environmental and other technical consulting services
376	Scientific research and development services
377	Advertising and related services
380	All other miscellaneous professional scientific and technical services
381	Management of companies and enterprises
382	Employment services
384	Office administrative services
385	Facilities support services
386	Business support services
387	Investigation and security services
388	Services to buildings and dwellings
389	Other support services
391	Elementary and secondary schools
392	Junior colleges colleges universities and professional schools
393	Other educational services
414	Automotive repair and maintenance except car washes
415	Car washes
416	Electronic and precision equipment repair and maintenance

417	Commercial and industrial machinery and equipment repair and maintenance
418	Personal and household goods repair and maintenance
419	Personal care services
420	Death care services
421	Dry-cleaning and laundry services
422	Other personal services
423	Religious organizations
424	Grantmaking giving and social advocacy organizations
425	Civic social professional and similar organizations
426	Private households
427	Postal service
429	Other Federal Government enterprises
432	Other state and local government enterprises
433	Not an industry (Used and secondhand goods)
434	Not an industry (Scrap)
435	Not an industry (Rest of the world adjustment)
436	Not an industry (Noncomparable imports)
437	Employment and payroll for SL Government Non-Education
438	Employment and payroll for SL Government Education
439	Employment and payroll for Federal Non-Military
440	Employment and payroll for Federal Military
402	Performing arts companies
403	Spectator sports
404	Promoters of performing arts and sports and agents for public figures
405	Independent artists writers and performers
406	Museums historical sites zoos and parks
407	Fitness and recreational sports centers
408	Bowling centers
409	Amusement parks arcades and gambling industries
410	Other amusement and recreation industries
383	Travel arrangement and reservation services
411	Hotels and motels including casino hotels
412	Other accommodations
413	Food services and drinking places