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Tools for Open Source, Subnational CGE Modeling with an Illustrative Analysis of Carbon Leakage

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This paper introduces the Wisconsin National Data Consortium (WiNDC) framework for producing self-consistent accounts based on publicly available datasets that can be used in sub-national economic equilibrium analysis in the United States. We describe the process used to generate regional social accounting matrices and a calibrated static multi-regional, multi-sectoral computable general equilibrium model conformal with the constructed dataset. As illustration, we show how the core model can be applied for the analysis of energy-environment issues. We use an energy-economy extension of the core model to assess the effectiveness of several state level greenhouse gas mitigation proposals. Sub-national abatement measures result in carbon leakage – mandated reductions in controlled areas may be vitiated by increased emissions in uncontrolled jurisdictions. Using a WiNDC-based model, we calculate leakage rates and show how these depend on the underlying trade model. Our calculations demonstrate the importance of both data and modeling assumptions for the simulation of policy experiments.

JEL codes: C6, C8, D5, Q5, R1.

Keywords: Computable General Equilibrium Models; Applied Economic Analysis; Multi-regional Models; Air Pollution; Regional Economies.

1. Introduction

Economists use models to perform economic policy experiments. Only a subset of possible questions are answerable using models, to some extent because the time frame for analysis is too short for organizing the requisite data. Computable general equilibrium (CGE) models are a type of model which are well suited for assessing the economy wide implications of policy changes. CGE models align

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an Arrow-Debreu general equilibrium representation of the economy with constructed input output tables describing all market transactions between producers and consumers in a given space.[1] In the United States, publicly available input output tables are provided by the Bureau of Economic Analysis (BEA) at the national level. Researchers interested in modeling the sub-national impacts of policy changes must look for other data options which can be expensive and inflexible in construction. These barriers to entry restricts the production of economic research and can complicate efforts to disentangle the impact that underlying input data has on modeling outcomes.[2] In this paper, we offer an alternative means of analysis by introducing a set of tools that construct and employ sub-national input output tables based on publicly available data sources. Our approach facilitates sensitivity analyses with respect to structural features in the underlying data. We demonstrate this capability with simulations assessing piecemeal state-level climate policy measures. We find that carbon leakage rates are sensitive to model and data related assumptions. This result is relevant to the ongoing policy debate on efficiently addressing climate policy in the absence of federal action.

This paper introduces the WiNDC (Wisconsin National Data Consortium[3]) modeling framework comprised of both a transparent and openly available data build routine and complementary modeling environment. The build routine relies on a set of sub-routines written in GAMS (General Algebraic Modeling System) that produce micro-consistent regionalized economic accounts encompassing the entire United States from 1997-2016.[4] We disclose all needed assumptions in the sub-

[1] The modeling environment has numerous applications across the economics literature; for instance, in trade (e.g. Harrison, Rutherford, and Tarr (1997); Hertel (1997); Balistreri, Hillberry, and Rutherford (2011)), energy (e.g. Böhringer and Löschel (2006); Böhringer and Rutherford (2008); Abrell and Rausch (2016)), environment (e.g. Jorgenson and Wilcoxen (1990); Böhringer, Carbone, and Rutherford (2016, 2018)), and water/agriculture (e.g. Berck, Robinson, and Goldman (1991); Robinson et al. (1993); Calzadilla, Rehdanz, and Tol (2010)).

[2] The standard data source for subnational CGE modeling in the United States is IMPLAN (for more information on how to use this data, see Rutherford and Schreiber (2016)). Because no federally produced datasets exist, sub-national input output tables in the United States are constructed using available regional economic data. In this paper, we illustrate that the construction process involves numerous assumptions that can potentially impact the ultimate results of an analysis. Understanding result sensitivity to assumptions is an important step in characterizing the range of impacts both internally to a given model and across models (see Barron et al. (2018) for a model comparison exercise from the Energy Modeling Forum that discusses these challenges).

[3] The consortium has been established to facilitate the creation and updating of an open source multi-sectoral, multi-regional economic dataset for the United States. A list of supporting institutions and most recently available versions of the dataset and models can be found on the website: windc.wisc.edu.

[4] This was true at the time of writing. Updates provided by the BEA on national level

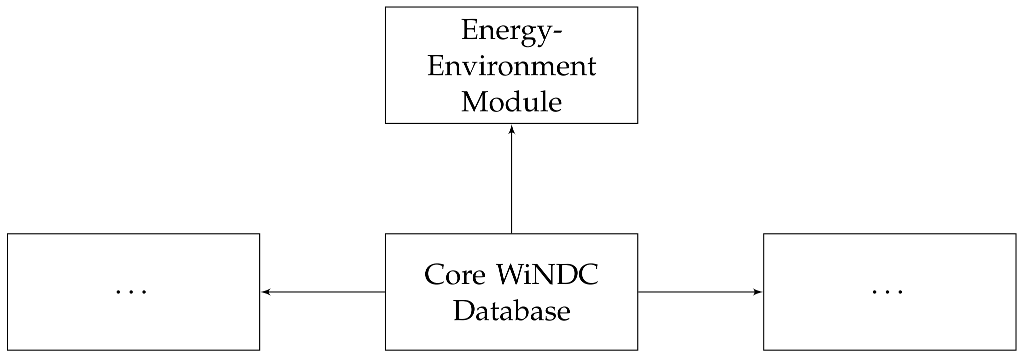

Figure 1. WiNDC modules

Notes: Data modules reflect a reconciliation between the core WiNDC dataset and external data sources. We include the energy-economy model as illustration of how the dataset can be applied for energy/environmental policy applications.
Source: Authors illustration's.

routines of the build routine and illustrate them throughout the text of this paper (e.g. regional datasets used, matrix balancing techniques, regionalization techniques). We also describe a modeling framework that complements the constructed set of regional economic accounts. The model is a calibrated multi-regional, multi-sector computable general equilibrium model that provides a foundational structure for specific empirical applications. The aim of WiNDC is to make evidence based regional economic research more accessible and to provide a transparent and basic structure of analysis that allows for comparisons of competing assumptions.

The data build distinguishes between producing a *core* dataset and datasets with subsequent extensions for specific policy analyses. The core dataset is based on the BEA summary files which include information on 71 sectors in the economy (see Appendix A). This core dataset serves as the basis for any further manipulations of the data. The package provides the tools for (dis)aggregating and/or recalibrating the dataset. The recalibration tools, collectively referred to as modules, reconcile the core WiNDC dataset with known external data as illustrated in Figure 1. This paper describes a module tailored for energy-environment applications. For this module we re-calibrate the core database to match State Energy Data System (SEDS) energy demands and prices. We also supplement the use of fossil based goods with carbon emissions. In addition, we provide a gravity based method for generating state level bilateral trade flows for all sectors and regions in the energy-focused aggregation.

The recalibrated dataset is used to assess the effectiveness of state level climate proposals. Since the US left the Paris Agreement there are limited federal requirements on greenhouse gas emissions. Subsequently, certain state and city leaders

supply and use tables provide the needed inputs for extending this time series.

showed an increased interest for sub-national policies addressing climate change. Historically, states have had mixed success in implementing sub-national climate policy. The Regional Greenhouse Gas Initiative and California's AB-32 are the only two active state level policies. Other states (Massachusetts, New York, Oregon, Rhode Island, Vermont, and Washington) had policy proposals for introducing state level carbon taxes, but these were never signed. The response to the federal government reneging on the Paris Agreement, however, has seen coalitions of state governors and city mayors commit to the goals of the agreement without federal mandates.

The effectiveness of sub-national efforts to reduce overall carbon emissions will be determined, in part, by leakage. Carbon leakage can occur when energy intensive production relocates away from regulated regions. This increases emissions in the unregulated regions and reduces the overall emissions impact of the policy. We calculate leakage rates induced by a 20% reduction in statewide emissions for a variety of state level policy proposals. As states are unable to impose border sanctions, levels of carbon leakage will be determined by relative prices, electricity trade, fossil fuel prices and factor mobility (Caron et al., 2015). Our primary mechanism to assess leakage rates is changes in trade due to relative prices in goods. Bottom-up representations of electricity trade that model the physics of electricity has been shown to be an important determination of the overall impacts of climate policy (Lanz and Rausch, 2011), though this is beyond the scope of the current analysis. Rather, we assess leakage rates under alternative assumptions on the structure of production and the underlying trade model. We find that increasing substitution possibilities in the production function mitigate leakage rates. We also compare leakage outcomes between two characterizations of trade: bilateral or a pooled national market. Leakage rates in the pooled model are higher than in the model with bilateral trade, since the pooled model effectively characterizes trade between states as perfect substitutes.[5] These calculations illustrate the importance of both data and modeling based assumptions on the outcomes of policy experiments.

The remainder of the paper is organized as follows. We present background information on available subnational accounts in the United States in Section 2. In Section 3 we present an overview of the sub-routines in the WiNDC build stream. We then describe the complementary computable general equilibrium model in Section 4. The model is described as a mixed complementarity problem (MCP) with the associated code provided in both MPSGE (Mathematical Programming

[5] These points have been found in other contexts. For instance, Antimiani, Costantini, and Paglialunga (2015) find that lower substitution possibilities in energy inputs increases the cost of carbon abatement efforts. Moreover, while not explicitly covering the difference between a pooled market and explicit bilateral trade, Keeney and Hertel (2009) find that trade elasticities used in the formulation of bilateral trade is of critical importance in the cost of biofuels policies.

Software for General Equilibrium) and MCP. In Section 5 we introduce the energy-environment module and demonstrate how the modeling framework can be used to explore the effectiveness of state level climate policies. We conclude in Section 6.

2. Background

Analysts seeking subnational detail in models of the United States face limited options. These options have historically been composed of a mixture of proprietary datasets that can be expensive and inflexibly constructed and customized data disaggregation using ad hoc routines.

The most widely used data source for subnational social accounts is provided by IMPLAN. IMPLAN generates consistent subnational social accounts using a proprietary build process based on public datasets. Aside from the numerous region specific analyses that use this data (e.g. Watson and Davies (2011)), a number of modeling groups use IMPLAN to characterize explicit regional impacts in a national model setting. A non-exhaustive list of CGE models that use this data include USREP (United States Regional Energy Policy model (Yuan et al., 2019)), SAGE (SAGE is an Applied General Equilibrium model (Marten, Schreiber, and Wolverton, 2019)), and ADAGE (The Applied Dynamic Analysis of the Global Economy model Woollacott, Cai, and Depro (2015)).

TERM (The Enormous Regional Model) is another proprietary data source for subnational social accounts provided through the Center of Policy Studies. TERM broadly refers to a data and modeling system designed to generate regionalized datasets and run a regional CGE model. The framework has been applied to the United States (Wittwer and Horridge, 2010), China (Horridge and Wittwer, 2008) and Australia (Horridge, Madden, and Wittwer, 2005) and uses an analogous process for regionalization as the methods presented in this paper. Rather than supply a dataset, TERM offers a proprietary build routine for producing subational accounts inclusive of a gravity estimated trade matrix that relies on national input output data and non-specific measures of each subnational economic structure (e.g. the distribution of sectoral output) (Horridge, 2012). A version of TERM-USA adapted towards better capturing the impacts of trade policy is described in Wittwer (2017a).

Outside of proprietary options, many researchers have opted to construct their own sets of subnational input output accounts (for instance, see Sue Wing and Kolodziej (2008)). While these efforts are similar in scope to the tools illustrated in this paper, there is likely considerable heterogeneity in practical implementation making comparisons across modeling efforts challenging. Moreover, often times the modeling is the focal point of the research, and underlying data used for calibration can be seen as an afterthought. This paper routinizes these construction efforts in an open source and transparent way and aims to create consistency in subational economic accounts used in equilibrium modeling in the United States.

Table 1. WiNDC data sources

Source	Description	ID	URL	Years
Bureau of Economic Analysis	Supply and Use Tables	*BEA*	https://www.bea.gov/industry/io_annual.htm	1997-2017
	Gross State Product	*GSP*	https://www.bea.gov/newsreleases/regional/gdp_state/qgsp_newsrelease.htm	1997-2016
	Personal Cosumer Expenditures	*PCE*	https://www.bea.gov/newsreleases/regional/pce/pce_newsrelease.htm	1997-2017
Census Bureau	Commodity Flow Survey	*CFS*	https://www.census.gov/econ/cfs/	2012
	State Government Finance	*SGF*	https://www.census.gov/programs-surveys/state/data/tables.All.html	1997-2016
	State Exports/Imports	*UTD*	https://usatrade.census.gov	2002-2016
Energy Information Administration	State Energy Data System	*SEDS*	https://www.eia.gov/state/seds/	1963-2016

Notes: Years indicates the *usable* years of available data across data sources. For instance, state level gross product is available for 2017 but has many hidden entries.

3. Data reconciliation

The build routine structure is summarized in Figure 2. The figure is segmented between national data reconciliation and regional disaggregation. Subsequent text follows this ordering. National data processing requires the conversion of BEA tables into a GAMS readable format, mapping set elements, partitioning tables into sub-matrices and CGE based parameters and enforcing micro-consistency.[6] "Regionalization" is characterized by our process of generating a multi-regional database from a set of consistent national files based on proportional scaling. Once the national-level data has been run through the initial matrix balancing routines, no further optimization methods are required. The subroutines with brief descriptions are listed in Appendix B. Each subroutine is called in the build stream in the order that it appears in the appendix. The core dataset is produced by step (8).

All source data required for producing sub-national economic input output tables are included in Table 1. The first column lists the governmental organizations that provide the data: the Bureau of Economic Analysis (BEA), the Census Bureau, and the Energy Information Administration (EIA). Descriptions of the datasets, datasets IDs and the respective website links are given in the middle columns. The final column indicates the range of years for which data is available.

3.1 National data reconciliation

The WiNDC data build begins by reconciling multi-year national level use and supply tables from the Bureau of Economic Analysis. The GAMS programming language relies on declared parameters (data) and variables indexed over sets. Raw BEA data are read as singular data structures, which are subsequently partitioned into sub-matrices based on specific row and column subsets. Table 2 reports all sets used within the routine (note that the regional set, r, is used in subsequent sections). The listed sets correspond to row or column indices of the supply and/or use tables. Sets s and g denote aliased sets for the 71 sectors and commodities

[6] Notably, national tables require row and column sums to match by default. However, there are quite a few instances of negative numbers in each table which general equilibrium models cannot handle.

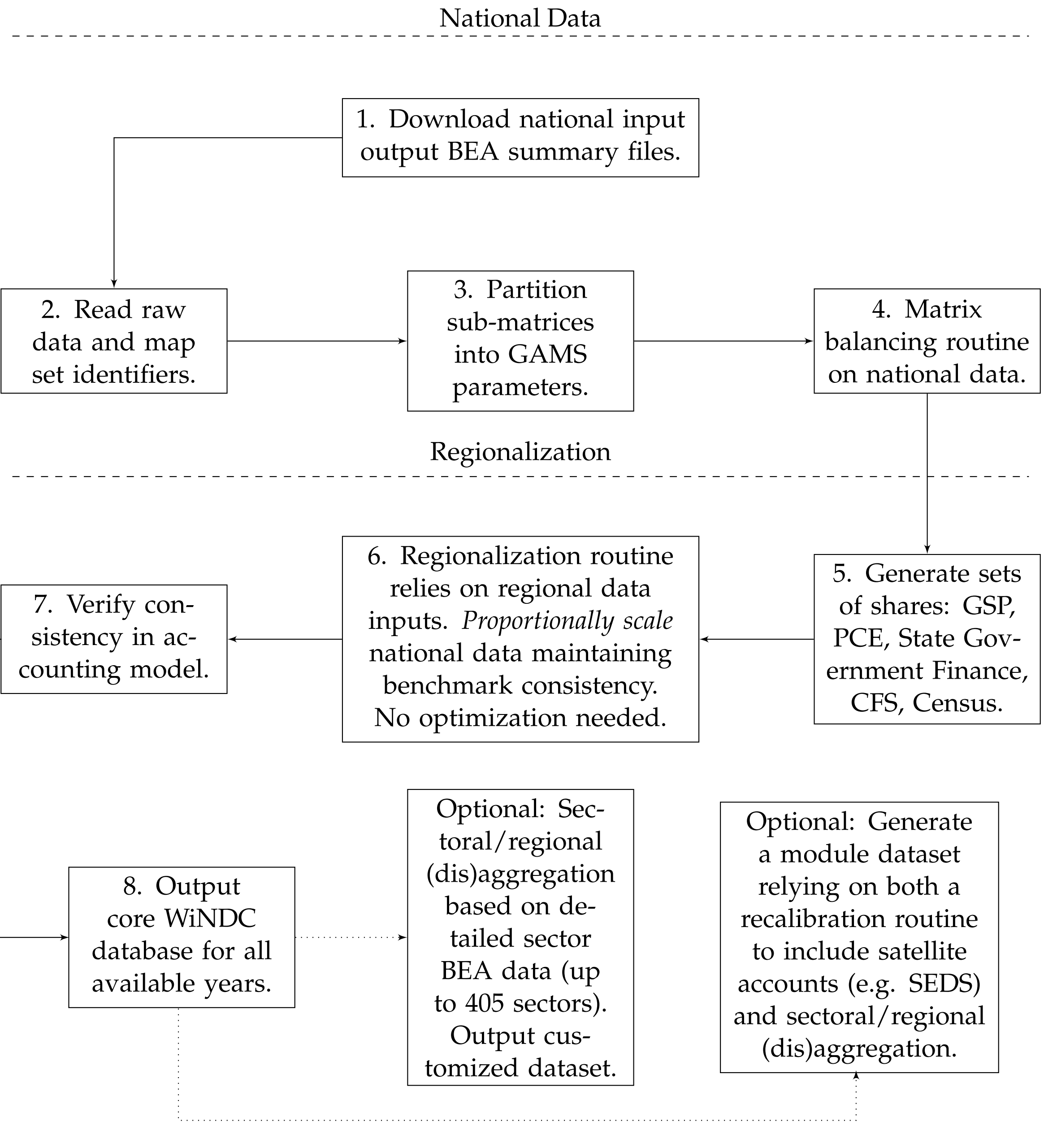

Figure 2. Build stream process

Notes: Dotted arrowed lines indicate optional portions of the build routine. The core routine ends after outputting a full set of computable general equilibrium parameters for every available year in the source data sets. Recalibrating and/or (dis)aggregating these accounts based on additional information is optional.

in the summary BEA data.[7] Value added, referred to by set va, contains wage payments, other taxes on production and gross operating surplus. Final demand accounts in the national data, denoted by fd, correspond to personal consumption expenditures, investment categories, and government (both federal and state levels) payments. Set m indicates margin adjustments for both trade and transport.

Table 2. Set notation

Type	Item	Description
Sets:	yr	Years
	s,g	Sectors/Goods
	m	Margin type
	va	Value added components
	fd	Final demand accounts
	r	Regions

Source: Authors' own set notation.

Using these subsets, we partition the annual supply and use tables into CGE parameters. National level parameters are described in Table 3. Data parameters are scaled to be in *10s of billions of dollars*. Sectoral supply is characterized by the first quadrant of the supply table which provides data on byproducts. For a given sector s and good g, the parameter $\tilde{ys}_{yr,s,g}$ denotes a matrix of annual output levels. Intermediate demand describing the material inputs needed to produce sectoral output is defined by the first quadrant of the use table. Final demand payments and exports of goods g are captured by the second quadrant of the use table. Value added by component va for sectoral production s and tax payments are partitioned from the third quadrant. Imports, margins (supply of margins are negative in the data and positive for margin demands) and tax payments for each commodity are partitioned from the second quadrant of the supply table. Average tax (duty) rates are subsequently defined based on overall tax payments relative to total input (import) demand.

Given the raw data parameters, we formulate other composite CGE parameters based on accounting identities needed in our modeling framework. Gross output is defined as total production net of margin supplies (household production is defined as negative payments).

$$\tilde{y}_{yr,g} = \sum_{s} \tilde{ys}_{yr,s,g} + \tilde{fs}_{yr,g} - \sum_{m} \tilde{ms}_{yr,g,m} \quad \forall \quad (yr, g) \tag{1}$$

The Armington supply parameter, $\tilde{a}_{yr,g}$, is defined as the total value of goods pur-

[7] See Appendix A, Table A.1 for a list of core economic sectors.

Table 3. Annual national level partitioned parameters from BEA data

Parameter	GAMS Code	Description
$\tilde{ys}_{yr,s,g}$	`ys0(yr,s,g)`	Sectoral supply (with byproducts)
$\tilde{y}_{yr,s}$	`y0(yr,s)`	Gross output (net margin supply)
$\tilde{fs}_{yr,g}$	`fs0(yr,g)`	Household production
$\tilde{id}_{yr,g,s}$	`id0(yr,g,s)`	Intermediate input demand
$\tilde{va}_{yr,va,s}$	`va0(yr,va,s)`	Value added factor demand
$\tilde{x}_{yr,g}$	`x0(yr,g)`	Foreign exports
$\tilde{m}_{yr,g}$	`m0(yr,g)`	Imports
$\tilde{ms}_{yr,g,m}$	`ms0(yr,g,m)`	Margin supply
$\tilde{md}_{yr,m,g}$	`md0(yr,m,g)`	Margin demand
$\tilde{a}_{yr,g}$	`a0(yr,g)`	Armington supply
$\tilde{ta}_{yr,g}$	`ta0(yr,g)`	Tax (subsidy) rate on intermediate demand
$\tilde{tm}_{yr,g}$	`tm0(yr,g)`	Import tariff rate
$\tilde{fd}_{yr,g,fd}$	`fd0(yr,g,fd)`	Final demand payments
$\tilde{bop}_{yr}$	`bopdef0(yr)`	Balance of payments

Notes: We use $\tilde{\ }$ to indicate national data parameters. In subsequent sections, $\bar{\ }$ is used to indicate associated regionalized parameters.
Source: Authors parameter notation.

chased as both final input and consumption demand.

$$\tilde{a}_{yr,g} = \sum_{s} \tilde{id}_{yr,g,s} + \sum_{fd} \tilde{fd}_{yr,g,fd} \quad \forall \quad (yr, g) \tag{2}$$

The balance of payments, $\tilde{bop}_{yr}$, is defined by the overall difference in value between total imports and total exports.

$$\tilde{bop}_{yr} = \sum_{g} \left(\tilde{m}_{yr,g} - \tilde{x}_{yr,g} \right) \quad \forall \quad (yr, g) \tag{3}$$

The reference set of partitioned data parameters is assumed to reflect a benchmark equilibrium. An equilibrium is characterized by three sets of conditions in a canonical competitive general equilibrium framework: profits cannot be greater than zero, markets must clear and incomes must balance with expenditures. Given these requirements, certain accounting identities must hold in the data to properly calibrate a model. The subroutine, `calibrate.gms`, ensures that these conditions hold by using optimization based matrix balancing techniques. This routine works using the GAMS facilities *savepoint* and *loadpoint*. Following the initial solve of each problem, the solution is stored in a temporary directory. This method allows subsequent runs of the problem to start from a previous solution point and thus minimizes the time of computations.

Zero profits must hold in sectoral production and the absorption and allocation of goods in the national economy. Zero profit in sectoral production requires that the value of supply equals the total value of the cost of production for each sector s.

$$\sum_{g} \tilde{ys}_{yr,s,g} = \sum_{g} \tilde{id}_{yr,g,s} + \sum_{va} \tilde{va}_{yr,va,s} \quad \forall \quad (yr, s) \tag{4}$$

The composition of the goods market must also satisfy a zero profit condition. The total value of goods demanded via intermediate inputs and final demand and the value of goods that are exported equal the value of domestically produced goods, imported goods and trade margins.

$$\left(1 - \tilde{ta}_{yr,g}\right) \tilde{a}_{yr,g} + \tilde{x}_{yr,g} = \tilde{y}_{yr,g} + \left(1 + \tilde{tm}_{yr,g}\right) \tilde{m}_{yr,g} + \sum_{m} \tilde{md}_{yr,m,g} \quad \forall \quad (yr, g) \tag{5}$$

Market clearance conditions must hold in factor and goods markets. Multiple goods markets exist based on the location of production, the absorption into the Armington supply and margin use. As factor payments are not differentiated between agent types in the national data, we refrain from explicit representation. Domestically produced goods through household and sectoral production must equal gross output demand in the absorption of goods and supply of margins.

$$\sum_{s} \tilde{ys}_{yr,s,g} + \tilde{fs}_{yr,g} = \tilde{y}_{yr,g} + \sum_{m} \tilde{ms}_{yr,g,m} \quad \forall \quad (yr, g) \tag{6}$$

Trade and transport margins are generated by the retail and transport sectors and demanded by the absorption of imported and domestically produced goods.

$$\sum_{g} \tilde{ms}_{yr,g,m} = \sum_{g} \tilde{md}_{yr,m,g} \quad \forall \quad (yr, m) \tag{7}$$

Foreign exchange is characterized by imports, exports and the balance of payments. Given the construction of $\tilde{bop}_{yr}$ in equation 3, this holds automatically.

$$\sum_{g} \tilde{x}_{yr,g} + \tilde{bop}_{yr} = \sum_{g} \tilde{m}_{yr,g} \quad \forall \quad yr \tag{8}$$

Finally, the total use of goods via intermediate input demand or final consumption must equal the amount supplied via the Armington supply. This holds by equation 2.

The remaining equilibrium assumption requires that endowment income must satisfy the total value of demand expenditures. The national level data does not provide information on transfers between agents. Income balance is expressed collectively by including factor and tax income and expenditure sources.

$$\sum_{fd,g} \tilde{fd}_{yr,g,fd} = \sum_{g} \tilde{fs}_{yr,g} + \tilde{bop}_{yr} + \sum_{va,s} \tilde{va}_{yr,va,s} + \sum_{g} \left(\tilde{ta}_{yr,g}\tilde{a}_{yr,g} + \tilde{tm}_{yr,g}\tilde{m}_{yr,g}\right) \quad \forall \quad yr \tag{9}$$

These identities are enforced through matrix balancing techniques. Optimization based matrix balancing problems are formulated using objective functions that penalize deviations from available data while satisfying accounting identity constraints. In the build routine, we provide two techniques to test the sensitivity of different objective functions in the resulting micro-consistent dataset. The first option is formulated based on a least squares quadratic objective function. For index pairings which have positive data entries, a weighted quadratic penalty is used which minimizes the percent difference between observable data. By applying a weight corresponding to the size of the initial data element, the program seeks to minimize deviations for larger numbers. In instances where parameters are zero, we impose a linear zero penalty weight to limit any changes from zero in the resulting solution. This problem is written generally in square format, using set indices (r, c) to denote a particular row and column element.[8] Let Φ_{rc} denote the subset of (r, c) with non-zero elements, Φ^c_{rc} denote its converse, let γ represent a positive penalty on zero elements, $\tilde{a}_{rc}$ available data and A_{rc} its corresponding variable. The quadratic program is defined as follows, with $F_i(\cdot) = 0$ denoting the set of accounting identity constraints:

$$
\begin{aligned}
\min_{A_{rc}} \quad & \sum_{\Phi_{rc}} |\tilde{a_{rc}}| \left(\frac{A_{rc}}{\tilde{a_{rc}}} - 1 \right)^2 + \gamma \sum_{\Phi^c_{rc}} A_{rc} \\
\text{s.t} \quad & F_i(A, \tilde{a}) = 0 \quad \forall i
\end{aligned}
$$

The second option is a piecewise hybrid approach based on Huber (1964). Since the least squares objective function is sensitive to outliers and does not preclude values going to zero, we formulate an objective function which is piecewise and dependent on deviations from a target value. This piecewise objective function adds a log term to penalize values which go to zero. This could be an important feature of the calibration strategy if small economic values are a significant dimension of the intended analysis. For instance, in energy and environmental applications, energy value shares are examples of data that tend to be economically small for transactions that are environmentally important. These coefficients must be retained in the calibration routine if we are to use the model to evaluate climate policy. Given the definitions presented in the least squares problem formulation, let θ be the cutoff point for the linear penalty given large increases of the reference value, and let ψ denote the cutoff point for large decreases relative to the reference level. Then the hybrid problem is formulated as follows:

$$
\begin{aligned}
\min_{A_{rc}} \quad & \sum_{rc} L(A_{rc}, \tilde{a_{rc}}) \\
\text{s.t} \quad & F_i(A, \tilde{a}) = 0 \quad \forall i \\
\text{where } L(A_{rc}, \tilde{a_{rc}}) = & \begin{cases} \tilde{a_{rc}} \theta \left(\frac{A_{rc}}{\tilde{a_{rc}}} - 1 \right) & \frac{\tilde{A_{rc}}}{\tilde{a}_{rc}} - 1 \geq \theta \\ \tilde{a_{rc}} \left(\frac{A_{rc}}{\tilde{a_{rc}}} - 1 \right)^2 & \theta \geq \frac{\tilde{A_{rc}}}{\tilde{a}_{rc}} - 1 \geq -\psi \\ \tilde{a_{rc}} \psi (1 - \psi) \log \left(\frac{A_{rc}}{\tilde{a_{rc}}} \right) & \frac{\tilde{A_{rc}}}{\tilde{a}_{rc}} - 1 \leq -\psi \end{cases}
\end{aligned}
$$

The least squares formulation is solved as a quadratically constrained program

[8] In practice, however, we have separate terms for each endogenized parameter value.

using the CPLEX solver and the hybrid formulation is solved as a nonlinear program using CONOPT. Each objective function produces minimal changes to the underlying data. Figure 3a illustrates the annual aggregate deviations from the benchmark data by optimization method (least squares relative to the Huber-hybrid method) and the percent deviation between both optimization frameworks. Both frameworks produce nearly identical solutions. The optimal percent change in the data ranges from -0.06% to 0.17% from year to year. Figure 3b reports the elapsed time needed for each solver to find the optimal solution.[9] The least squares formulation is the more efficient method. Because matrix balancing techniques are applied to the national data set with summary level sectors, many of the potential issues that may warrant additional complexity are not present (e.g. small numbers that may be particularly economically significant).[10]

3.2 Subnational regionalization

This routine aims to provide a comprehensive dataset of the United States with specific representation of sub-national regions. The process of regionally disaggregating the national data relies on *proportional scaling* rather than optimization. Given data on the composition of the regional economy, we generate shares for associated CGE parameters to disaggregate the set of fully micro-consistent national accounts. This method has a number of advantages. While matrix balancing presents an alternative method to construct regional accounts, the technique requires little economics, especially when limited information is known on regional economic structures. The sharing method constrains the sum of regional data to national totals and perhaps most importantly, provides a measure of transparency. In the United States, there is limited information outside of those presented in Table 1. Due to this dearth of information, controlling the sharing of economic parameters

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[9] This test was performed on an Intel Xeon CPU with 2.30GHz and 16gb of ram.

[10] Entropy methods akin to Golan, Judge, and Robinson (1994) and Robinson, Cattaneo, and El-Said (2001) represent an alternative matrix balancing formulation. The basic entropy method formulates a problem similar to those presented in this paper. It relies on an objective function of the form: $L(A_{rc}, \overline{a}_{rc}) = A_{rc} \ln \frac{A_{rc}}{\overline{a}_{rc}}$. Notably, this is not treated as a penalty function that minimizes loss, but rather one that minimizes the expected value of additional information. This treats the initial matrix of coefficients as a prior distribution, with the resulting solution (A_{rc}) as the posterior. Robinson, Cattaneo, and El-Said (2001) provides methods for bounding the exercise with additional information on aggregates and estimating error terms when the initial matrix is unbalanced. The hybrid method presented in this paper is loosely based on these ideas by using the logarithmic function to prevent values from going to zero. As a measure of sensitivity, we compute the percent change in the data with an entropy objective function and find similar results to the methods presented above. Both the least squares and hybrid-huber loss function produce roughly a -0.1% decrease in the total level of the data, whereas entropy produces a 0.2% increase in the total level of the data (using 2016 data). The time needed to solve the entropy method was nearly double that of the hybrid method.

(a) % Change in the data

(b) Time to solve

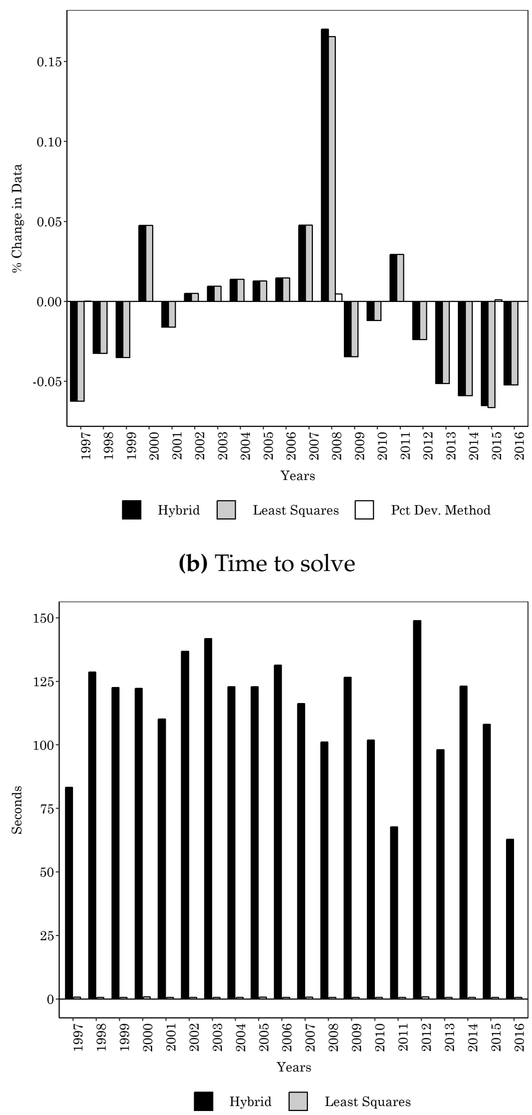

Figure 3. National data matrix balancing diagnostics

Source: Authors calculations.

explicitly provides a defensible mechanism rooted in the economic structure of the proposed modeling framework. Notably, however, proportionally scaling the national data will produce regional estimates that may not precisely match reported statistics.

In all instances aside from the trade data, shares are generated to sum to unity across regions. As the mapping between regional sector level data and national

Table 4. Parameters in the regional CGE model

Parameter	GAMS Code	Description
$\bar{ys}_{yr,r,s,g}$	`ys0(yr,r,s,g)`	Sectoral supply (with byproducts)
$\bar{id}_{yr,r,g,s}$	`id0(yr,r,g,s)`	Intermediate demand
$\bar{ld}_{yr,r,s}$	`ld0(yr,r,s)`	Labor demand
$\bar{kd}_{yr,r,s}$	`kd0(yr,r,s)`	Capital demand
$\bar{cd}_{yr,r,g}$	`cd0(yr,r,g)`	Final demand
$\bar{yh}_{yr,r,g}$	`yh0(yr,r,g)`	Household production
$\bar{g}_{yr,r,g}$	`g0(yr,r,g)`	Government demand
$\bar{i}_{yr,r,g}$	`i0(yr,r,g)`	Investment demand
$\bar{s}_{yr,r,g}$	`s0(yr,r,g)`	Aggregate supply
$\bar{xn}_{yr,r,g}$	`xn0(yr,r,g)`	National supply
$\bar{xd}_{yr,r,g}$	`xd0(yr,r,g)`	State level supply
$\bar{x}_{yr,r,g}$	`x0(yr,r,g)`	Foreign exports
$\bar{a}_{yr,r,g}$	`a0(yr,r,g)`	Armington supply
$\bar{m}_{yr,r,g}$	`m0(yr,r,g)`	Imports
$\bar{nd}_{yr,r,g}$	`nd0(yr,r,g)`	National demand
$\bar{dd}_{yr,r,g}$	`dd0(yr,r,g)`	State level demand
$\bar{bop}_{yr,r}$	`bopdef0(yr,r)`	Balance of payments
$\bar{ta}_{yr,r,g}$	`ta0(yr,r,g)`	Tax net subsidy rate on intermediate demand
$\bar{tm}_{yr,r,g}$	`tm0(yr,r,g)`	Import tariff
$\bar{md}_{yr,r,m,g}$	`md0(yr,r,m,g)`	Margin demand
$\bar{nm}_{yr,r,g,m}$	`nm0(yr,r,g,m)`	National margin supply
$\bar{dm}_{yr,r,g,m}$	`dm0(yr,r,g,m)`	State level margin supply

Source: Authors' parameter notation.

data (regional data tends to be more aggregated) is typically not 1-1, sector mappings are created to associate disaggregate sector level national data with the aggregated regional economic index.

Let $\alpha^{*}_{yr,r,s}$ be the regional sharing parameter associated with the $\star$ dataset, such that $\sum_r \alpha^{*}_{yr,r,s} = 1$. Table 4 provides a listing of all regional CGE parameters generated through the regional disaggregation process described in the computer programs. Gross State Product (GSP) data is used to disaggregate sectoral production accounts. We also use GSP data to calculate the regional share of labor relative to capital to distinguish regional production technologies. Let $\theta^{ls}_{yr,r,s} \in (0,1)$ denote the share of labor in total value added.[11] Using GSP shares maintains the zero-profit condition by region.[12]

$$\bar{ys}_{yr,r,s,g} = \alpha^{gsp}_{yr,r,s}\tilde{ys}_{yr,s,g} \quad \forall \quad (yr,r,s,g) \tag{10}$$

[11] We formulate labor shares according to averages (across years) in years with negative capital payments to enforce shares of less than 1.

[12] Note that we have compared the predicted labor demands using the proportional scaling technique relative to labor compensation reported by the BEA in the GSP data. In total, across regions and sectors, predicted labor demand is within roughly 1% of the reported measures. There is heterogeneity in regional and sectoral differences, however, ranging between 0-5% percent difference from reported levels in most cases.

$$\bar{id}_{yr,r,g,s} = \alpha^{gsp}_{yr,r,s} \tilde{id}_{yr,g,s} \quad \forall \quad (yr, r, g, s) \tag{11}$$

$$\bar{ld}_{yr,r,s} = \theta^{ls}_{yr,r,s} \alpha^{gsp}_{yr,r,s} \sum_{va} \tilde{va}_{yr,va,s} \quad \forall \quad (yr, r, s) \tag{12}$$

$$\bar{kd}_{yr,r,s} = \left(1 - \theta^{ls}_{yr,r,s}\right) \alpha^{gsp}_{yr,r,s} \sum_{va} \tilde{va}_{yr,va,s} \quad \forall \quad (yr, r, s) \tag{13}$$

Final demand categories are aggregated into either aggregate household consumption (C), investment (I) or government expenditures (G). The latter is a combination of federal, state and local spending on defense, infrastructure, education and equipment. Regional shares used for household final demand are based on the Personal Consumption Expenditure (PCE) dataset by the BEA and shares for government purchases are based on the State Government Finance (SGF) tables from the Census Bureau. Investment demand and household production are regionally disaggregated according to GSP data.

$$\bar{cd}_{yr,r,g} = \alpha^{pce}_{yr,r,g} \sum_{C \in fd} \tilde{fd}_{yr,g,fd} \quad \forall \quad (yr, r, g) \tag{14}$$

$$\bar{g}_{yr,r,g} = \alpha^{sgf}_{yr,r,g} \sum_{G \in fd} \tilde{fd}_{yr,g,fd} \quad \forall \quad (yr, r, g) \tag{15}$$

$$\bar{i}_{yr,r,g} = \alpha^{gsp}_{yr,r,g} \sum_{I \in fd} \tilde{fd}_{yr,g,fd} \quad \forall \quad (yr, r, g) \tag{16}$$

$$\bar{yh}_{yr,r,g} = \alpha^{gsp}_{yr,r,g} \tilde{fs}_{yr,g} \quad \forall \quad (yr, r, g) \tag{17}$$

These disaggregate parameters are used to calculate the regionalized Armington supply parameter similarly to the national accounting identity.

$$\bar{a}_{yr,r,g} = \bar{cd}_{yr,r,g} + \bar{g}_{yr,r,g} + \bar{i}_{yr,r,g} + \sum_{s} \bar{id}_{yr,r,g,s} \quad \forall \quad (yr, r, g) \tag{18}$$

Gross output can also be computed from regionalized parameters. Notably, we include margin supply in gross output (in the national parameter, gross output was net of margins), to distinguish margins generated through state level or national level demands.

$$\bar{s}_{yr,r,g} = \sum_{s} \bar{ys}_{yr,r,s,g} + \bar{yh}_{yr,r,g} \quad \forall \quad (yr, r, g) \tag{19}$$

Given a degree of freedom in dtermining trade totals, we use a mixture of state level export data from USA Trade Online (or UTD, from the Census Bureau) and gross state product to regionally disaggregate export totals. [13]

$$\bar{x}_{yr,r,g} = \alpha^{utd}_{yr,r,g}\tilde{x}_{yr,g} \quad \forall \quad (yr, r, g) \tag{20}$$

Without information on region tax rates, we assume that: $\bar{ta}_{yr,r,g} = \tilde{ta}_{yr,g}$ and $\bar{tm}_{yr,r,g} = \tilde{tm}_{yr,g}$. By defining the Armington supply, we calculate implicit shares based on regional absorption (which embed the differences in shares across data sources).

$$\alpha^{abs}_{yr,r,g} = \bar{a}_{yr,r,g} / \sum_{rr} \bar{a}_{yr,r,g} \quad \forall \quad (yr, r, g) \tag{21}$$

The regional absorption of goods are generated through imports, local and national supply and margins. Therefore, regional imports and margin demand are computed using the implicit share of regional absorption.

$$\bar{m}_{yr,r,g} = \alpha^{abs}_{yr,r,g}\tilde{m}_{yr,g} \tag{22}$$

$$\bar{md}_{yr,r,m,g} = \alpha^{abs}_{yr,r,g}\tilde{md}_{yr,m,g} \tag{23}$$

Given this configuration, there are instances where $\bar{s}_{yr,r,g} - \bar{x}_{yr,r,g} < 0$. For this reaseon, we create a parameter, $\bar{rx}_{yr,r,g}$, to indicate *re-exports*, where $\bar{rx}_{yr,r,g} = \bar{x}_{yr,r,g} - \bar{s}_{yr,r,g}$, when the total regional supply is smaller than regional exports for a given good. The regional balance of payments is calculated based on imports and exports (re-exports cancel out).

$$\bar{bop}_{yr,r} = \sum_{g} \left(\bar{m}_{yr,r,g} - \bar{x}_{yr,r,g}\right) \quad \forall \quad (yr, r) \tag{24}$$

From the *demand* side of the market, the difference between the value of the total regional absorption $((1 - \bar{ta})\bar{a})$ net of re-exports and imports plus margin demand must equal the maximum level of state (or nationally) sourced goods demand. Conversely, the maximum level of state (or national) supply is governed by the supply side of the market, namely, the difference between total supply and foreign exports net of re-exports. We let the supply and demand side of the market dictate the possible levels of state and nationally produced supply and demand. Let $\hat{dd}_{yr,r,g}$ denote the maximum *possible* level of state level goods demands.

$$\begin{aligned} \hat{dd}_{yr,r,g} = \min\{&(1 - \bar{ta}_{yr,r,g})\bar{a}_{yr,r,g} + \bar{rx}_{yr,r,g} - (1 + \bar{tm}_{yr,r,g})\bar{m}_{yr,r,g} - \sum_{m} \bar{md}_{yr,r,m,g}, \\ &\bar{s}_{yr,r,g} - (\bar{x}_{yr,r,g} - \bar{rx}_{yr,r,g})\} \quad \forall \quad (yr, r, g) \end{aligned} \tag{25}$$

In order to determine the share of the maximum which is represented by the parameter $\bar{dd}_{yr,r,g}$, we use data from the Commodity Flow Survey (CFS) for 2012. The

[13] USA Trade Online does not include a comprehensive list of sectors to cover all sectors from the national input output data. We assume that exports follow gross state product for the sectors that are not included.

CFS catalogs all commodity shipments between and within states.[14] Using these data, we characterize *regional purchase coefficients*, $\rho^{cfs}_{r,g}$, as the share of a given commodity's state demand relative to total national demand (from all states, included itself). For service sectors not included in the CFS, averages are used. Further, we set the RPC for utilities near unity. State level demand is determined by these regional purchase coefficients.

$$\bar{dd}_{yr,r,g} = \rho^{cfs}_{r,g} \hat{dd}_{yr,r,g} \quad \forall \quad (yr, r, g) \tag{26}$$

Goods demand from other national markets must satisfy the following closure condition, or the difference between the Armington supply (net of re-exports) and local and foreign demand for goods (net of margins).

$$\begin{aligned} \bar{nd}_{yr,r,g} =& (1 - \bar{ta}_{yr,r,g})\bar{a}_{yr,r,g} + \bar{rx}_{yr,r,g} - \bar{dd}_{yr,r,g} \\ &- (1 + \bar{tm}_{yr,r,g})\bar{m}_{yr,r,g} - \sum_m \bar{md}_{yr,r,m,g} \quad \forall \quad (yr, r, g) \end{aligned} \tag{27}$$

Margins are supplied either through the state or national supply of goods. Total margin supply, $\hat{ms}_{yr,r,g,m}$ can be characterized through shares generated from $\bar{md}_{yr,r,m,g}$.

$$\hat{ms}_{yr,r,g,m} = \frac{\sum_{g'} \bar{md}_{yr,r,m,g'}}{\sum_{r'g'} \bar{md}_{yr,r',m,g'}} \tilde{ms}_{yr,g,m} \tag{28}$$

The share of trade and transport margins can be calculated as follows: $\beta^{mar}_{yr,r,m,g} = \hat{ms}_{yr,r,g,m} / \sum_{m'} \hat{ms}_{yr,r,g,m'}$. We characterize the share of total margin supply coming from the state supply of goods relative to the national supply with these parameters using the supply and demand side of the market and the information on the state level demand relative to national demands using the regional purchase coefficient.

$$\begin{aligned} \bar{dm}_{yr,r,g,m} =& \min\{\rho^{cfs}_{r,g} \hat{ms}_{yr,r,g,m}, \\ & \beta^{mar}_{yr,r,m,g}(\bar{s}_{yr,r,g} - \bar{x}_{yr,r,g} + \bar{rx}_{yr,r,g} - \bar{dd}_{yr,r,g})\} \quad \forall \quad (yr, r, m, g) \end{aligned} \tag{29}$$

Margins from the national supply follow directly.

$$\bar{nm}_{yr,r,g,m} = \hat{ms}_{yr,r,g,m} - \bar{dm}_{yr,r,g,m} \quad \forall \quad (yr, r, m, g) \tag{30}$$

The regional and national supply must then be determined using margin supply and goods demand parameters previously computed.

$$\bar{xd}_{yr,r,g} = \sum_m \bar{dm}_{yr,r,g,m} + \bar{dd}_{yr,r,g} \quad \forall \quad (yr, r, g) \tag{31}$$

The national supply of goods follows from the difference in total supply and state

[14] Notably, these indicate *all* shipments, not origin and final destination. As such, the data includes state pairings for transshipments. Issues with the CFS are well documented in Wittwer (2017b).

and foreign supply (net of re-exports).

$$\bar{xn}_{yr,r,g} = \bar{s}_{yr,r,g} + \bar{rx}_{yr,r,g} - \bar{xd}_{yr,r,g} - \bar{x}_{yr,r,g} \quad \forall \quad (yr,r,g) \tag{32}$$

After the set of national data is regionally disaggregated, we run the constructed set of parameters through a series of consistency tests which verify the reference equilibrium for all available years of data.

3.3 Sectoral/regional customizations

Basic sector and regional customizations are possible once the core WiNDC database is constructed with 51 regions (states and the District of Columbia) and 71 sectors. Often a CGE analysis requires specific attention to particular region-sector pairings and an aggregated treatment of other sectors and regions for better numerical precision and faster computational speeds. Subroutines are provided that facilitate partial (or full) disaggregation of the 71 sectors based on the detailed BEA supply and use input output tables with 405 sectors and re-aggregation of other nonessential indices. For instance, if modeling an energy policy, splitting the aggregated utilities sector into its electricity, gas and water subcomponents may provide a needed level of detail while aggregating the service sectors into a composite sector would produce minimal influences on results and reduce the dimensionality of the model.

4. A Multi-regional multi-sectoral CGE model

The canonical, multi-regional, multi-sectoral computable general equilibrium model which complements the constructed set of regional economic parameters is formulated in a static framework. A single year of data must be chosen for model calibration (the year index will be subsequently suppressed). The variables required for the canonical model are described in Table 5. $Y_{r,s}$ reflects total production by sector s in region r, $X_{r,g}$ denotes the allocation of good g in region r to either the state, national or foreign market, $A_{r,g}$ represents the absorption of goods in region r for good g and $MS_{r,m}$ is margin supply of margin type m in region r. Each activity level variable is associated with zero profit accounting identities in the data.

$$Y_{r,s}: \quad \sum_g \bar{ys}_{r,s,g} - \sum_g \bar{id}_{r,g,s} - \bar{ld}_{r,s} - \bar{kd}_{r,s} = 0 \quad \forall \quad (r,s) \tag{33}$$

$$X_{r,g}: \quad \bar{x}_{r,g} - \bar{rx}_{r,g} + \bar{xn}_{r,g} + \bar{xd}_{r,g} - \bar{s}_{r,g} = 0 \quad \forall \quad (r,g) \tag{34}$$

$$A_{r,g}: \quad (1-\bar{ta}_{r,g})\bar{a}_{r,g} + \bar{rx}_{r,g} - \bar{nd}_{r,g} - \bar{dd}_{r,g} - (1+\bar{tm}_{r,g})\bar{m}_{r,g} - \sum_m \bar{md}_{r,m,g} = 0 \quad \forall \quad (r,g) \tag{35}$$

$$MS_{r,m}: \quad \sum_g \bar{md}_{r,m,g} - \sum_g \left(\bar{nm}_{r,g,m} + \bar{dm}_{r,g,m}\right) = 0 \quad \forall \quad (r,m) \tag{36}$$

Price variables are associated with market clearance accounting identities. We

Table 5. Nomenclature in the regional CGE model

Type	Item	Description
Activity Levels:	$Y_{r,s}$	Sectoral output
	$A_{r,g}$	Armington composite
	$X_{r,g}$	Supply allocation
	$MS_{r,m}$	Margin supply
Prices:	$p^{Y}_{r,g}$	Output market price
	$p^{A}_{r,g}$	Armington composite price index
	$p^{D}_{r,g}$	State level market price for goods
	p^{N}_{g}	National market price for goods
	p^{FX}	Foreign exchange rate
	p^{L}_{r}	Wage rates
	$p^{K}_{r,s}$	Capital rental rates
	$p^{M}_{r,m}$	Margins markup
Agents:	RA_r	Representative household income

Source: Authors' nomenclature.

distinguish between eight price categories. p^L_r denotes the regional wage rate, $p^K_{r,s}$ is the sector specific capital rental rate in region r for sector s, $p^Y_{r,g}$ denotes the output market price, $p^D_{r,g}$ is the state level market price for good g, p^N_g represents the price for good g from the national market, p^{FX} is the price of foreign exchange and p^M_{rm} denotes the price of margin type m in region r. Some of these accounting conditions hold trivially, but they are explicitly represented for completeness.

$$p^Y_{r,g}: \quad \sum_s \bar{ys}_{r,s,g} + \bar{yh}_{r,g} - \bar{s}_{r,g} = 0 \quad \forall \quad (r,g) \tag{37}$$

$$p^A_{r,g}: \quad \bar{a}_{r,g} - \sum_s \bar{id}_{r,g,s} - \bar{cd}_{r,g} - \bar{g}_{r,g} - \bar{i}_{r,g} = 0 \quad \forall \quad (r,g) \tag{38}$$

$$p^D_{r,g}: \quad \bar{xd}_{r,g} - \sum_m \bar{dm}_{r,g,m} - \bar{dd}_{r,g} = 0 \quad \forall \quad (r,g) \tag{39}$$

$$p^N_{g}: \quad \sum_r \left(\bar{xn}_{r,g} - \sum_m \bar{nm}_{r,g,m} - \bar{nd}_{r,g} \right) = 0 \quad \forall \quad (g) \tag{40}$$

$$p^{FX}: \quad \sum_{r,g} \left(\bar{x}_{r,g} - \bar{m}_{r,g} \right) - \sum_r \bar{bop}_r = 0 \tag{41}$$

$$p^L_{r}: \quad \sum_s \bar{ld}_{r,s} - \sum_s \bar{ld}_{r,s} = 0 \quad \forall \quad (r) \tag{42}$$

$$p^K_{r,s}: \quad \bar{kd}_{r,s} - \bar{kd}_{r,s} = 0 \quad \forall \quad (r,s) \tag{43}$$

$$p^M_{r,m}: \quad \sum_g \bar{md}_{r,m,g} - \sum_g \bar{md}_{r,m,g} = 0 \quad \forall \quad (r,m) \tag{44}$$

Income variables are associated with income balance accounting identities. We explicitly represent a representative regional household, holding fixed government and investment demand (RA_r denotes the income level of a representative regional household). This can be extended in case revenue recycling policy mechanisms are of interest. Given the regionalization routine outlined in this paper, regional household income ($\bar{adj}_r^{hh}$) adjustment parameters are necessary for redistributing incomes across regions in order to equate endowment incomes with reference demands. Note that: $\sum_r \bar{adj}^{hh}{}_r = 0$.

$$RA_r: \quad \sum_g \left(\bar{cd}_{r,g} + \bar{g}_{r,g} + \bar{i}_{r,g}\right) - \sum_g \bar{yh}_{r,g} - \sum_s \left(\bar{ld}_{r,s} + \bar{kd}_{r,s}\right) - \bar{bop}_r - \bar{adj}_r^{hh} - \sum_g \left(\bar{ta}_{r,g}\bar{a}_{r,g} + \bar{tm}_{r,g}\bar{m}_{r,g}\right) = 0 \quad \forall \quad (r) \tag{45}$$

These accounting identities can be visually represented in the context of a regional social accounting matrix in Table 6. Rows represent outputs or endowments for the associated condition (zero profit, market clearance or income balance) and columns denote inputs or demands. Rows/columns which are labeled with activity levels represent zero-profit accounting identities, those labeled with prices represent market clearance conditions and income balance identities can be characterized in the Agent column/row. The gray cell in the bottom right corner of the matrix characterizes the "fourth quadrant" which typically includes transfers between agents. The core WiNDC build refrains from constructing a set of transfers between agents, though this may be added as satellite information if distributional impacts of policy is of interest.

The regional economic flows are illustrated in Figure 4. Sectoral production ($Y_{r,s}$) is supplied with factors of production (capital and labor) by the representative agent (RA_r) and material inputs from the goods market ($A_{r,g}$). The resulting supply is sent to the allocation market ($X_{r,g}$) where total supply (including household production $\bar{yh}_{r,g}$) is distributed to the regional level market ($\bar{xd}_{r,g}$), the national market ($\bar{xn}_{r,g}$) or the foreign market ($\bar{x}_{r,g}$). Regional level supply is allocated either to margin formulation ($\bar{dm}_{r,m}$) or for regional demand of goods ($\bar{dd}_{r,g}$). The total pool of goods is a blend of regional goods, nationally supplied goods outside of region r ($\bar{nd}_{r,g}$) and imports ($\bar{m}_{r,g}$). Taxes on goods are allocated to the representative agent. The total pool of goods is allocated to final demanding agents ($\bar{cd}_{r,g}$, $\bar{g}_{r,g}$, $\bar{i}_{r,g}$) or to intermediate demand in sectoral production ($\bar{id}_{r,g,s}$).

4.1 The Primal Formulation

The identities given in the previous section represent the conditions that must hold in the *data* to reflect a benchmark equilibrium. However, they do not describe the behavior of agents in the model. We characterize the decentralized optimization problems of the subcomponents of the model in this section. Producers are assumed to maximize profit in a constant returns to scale environment (which we

Table 6. Regional social accounting matrix

		Production	Exports	Absorption Composite	Margins	Output Market	Regional Market	National Market	Domestic Composite	Factors	Margins Market	Trade	Agents
		$Y_{r,s}$	$X_{r,g}$	$A_{r,g}$	$M_{r,m}$	$p^Y_{r,g}$	$p^D_{r,g}$	p^N_s	$p^A_{r,g}$	$p^L_r, p^K_{r,s}$	$p^M_{r,m}$	P^{FX}	
Production	$Y_{r,s}$					$\bar{ys}_{r,s,g}$							
Exports	$X_{r,g}$						$\bar{xd}_{r,g}$	$\bar{xn}_{r,g}$				$\bar{x}_{r,g}$	
Absorption Composite	$A_{r,g}$								$\bar{a}_{r,g}$				
Margins	$M_{r,m}$										$\bar{md}_{r,m,g}$		
Output Market	$p^Y_{r,g}$		$\bar{s}_{r,g}$										
Regional Market	$p^D_{r,g}$			$\bar{dd}_{r,g}$	$\bar{dm}_{r,g,m}$								
National Market	p^N_g			$\bar{nd}_{r,g}$	$\bar{nm}_{r,g,m}$								
Domestic Composite	$p^A_{r,g}$	$\bar{id}_{r,g,s}$											$\bar{cd}_{r,g}$, $\bar{g}_{r,g}, \bar{i}_{r,g}$
Factors	$p^L_r, p^K_{r,s}$	$\bar{ld}_{r,s}, \bar{kd}_{r,s}$											
Margins Market	p^M_m			$\bar{md}_{r,m,g}$									
Trade	p^{FX}			$\bar{m}_{r,g}$									
Agents						$\bar{yh}_{r,g}$				$\bar{ld}_{r,s}, \bar{kd}_{r,s}$		$\bar{bop}_r$	

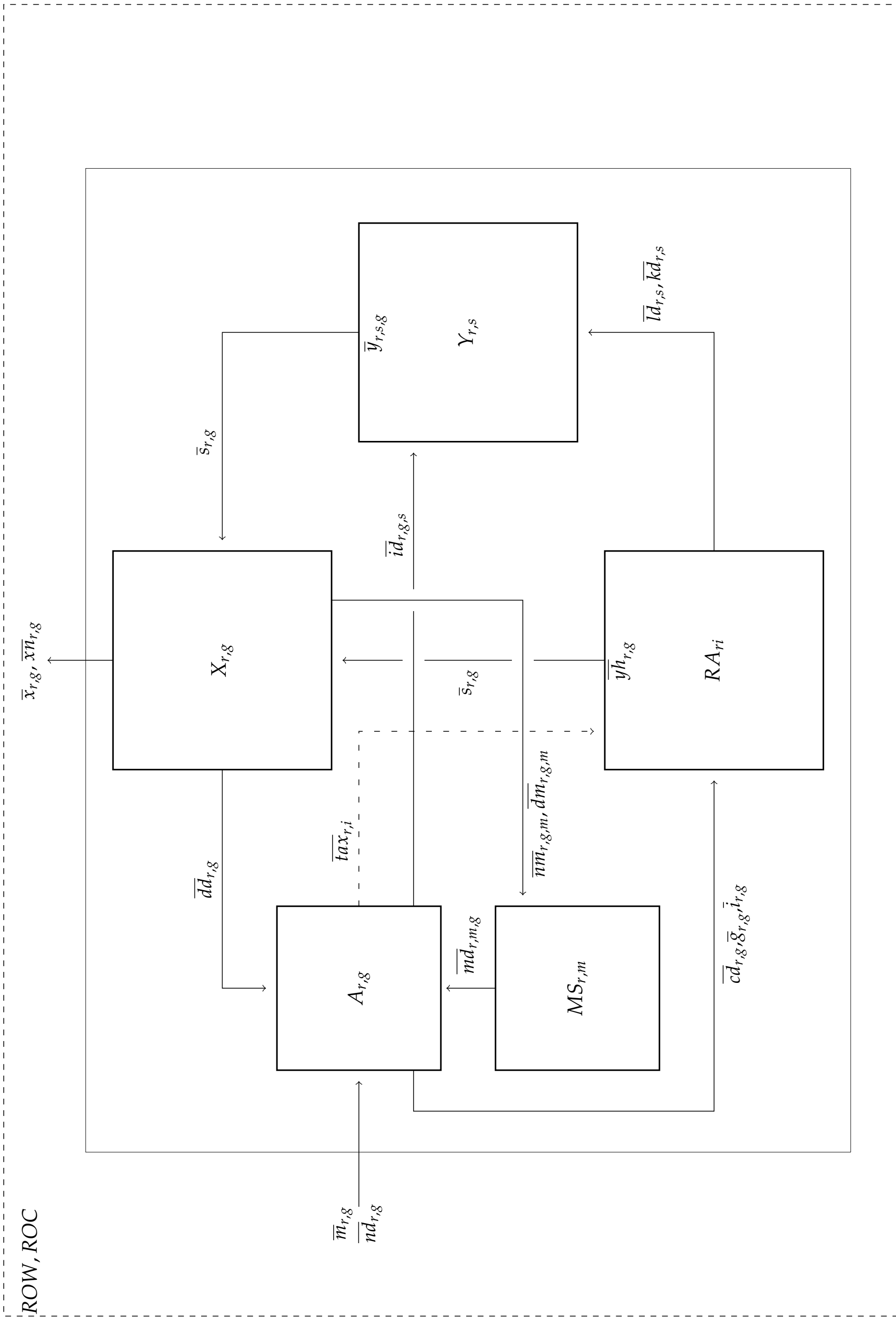

Figure 4. Regional economic structure

equivalently write as a cost minimization problem). Input choices for sector $Y_{r,s}$ are found by the following minimization problem. Note that these optimization problems solve for quantities in terms of prices. Data notation is used to describe variables without the overline.

$$\begin{aligned}
\min_{id,ld,kd} \quad & c^M_{r,s} + c^F_{r,s} \\
\text{s.t.} \quad & c^M_{r,s} = \sum_g p^A_{r,g} id_{r,g,s} \\
& c^F_{r,s} = p^L_r ld_{r,s} + p^K_{r,s} kd_{r,s} \\
& F^Y_{r,s}(id_{r,g,s}, ld_{r,s}, kd_{r,s}) = Y_{r,s}
\end{aligned}$$

The production function $F^Y(\cdot)$ is described by a nested constant elasticity of substitution (CES) form shown in the lower part of the tree diagram in Figure 5. We define the nesting structure using associated prices of input demands. Let σ denote the constant elasticity of substitution governing input trade offs in production, let $\sigma^{VA}_{r,s}$ represent the substitution elasticity between factors of production (assumed to be Cobb-Douglas), let $\sigma^M_{r,s}$ be the substitution elasticity between material inputs (assumed to be Leontief) and $\sigma^Y_{r,s}$ denotes the top level substitution elasticity between total value added and total material inputs (also assumed to be Leontief).

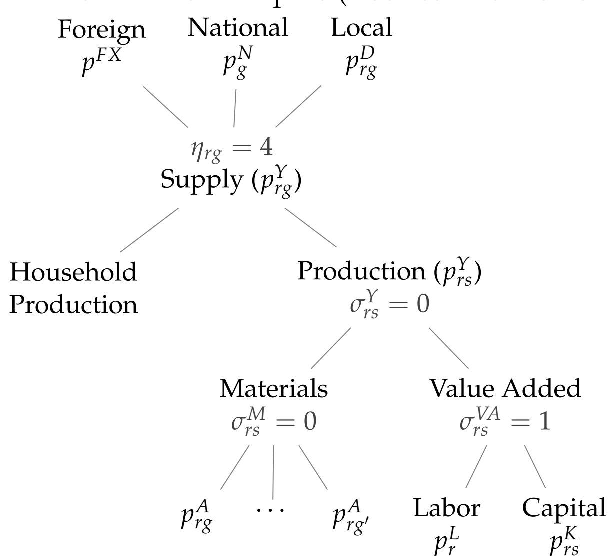

Figure 5. Production (CES) and supply (CET) structure

The allocation of supply to the foreign, national or state market arise from the following profit maximization problem.[15]

$$\begin{aligned} \max_{x,xn,xd,rx} \quad & p^{FX}(x_{r,g} - rx_{r,g}) + p^N_g xn_{r,g} + p^D_{r,g} xd_g \\ \text{s.t.} \quad & F^X_{r,g}(x_{r,g}, rx_{r,g}, xn_{r,g}, xd_{r,g}) = X_{r,g} \end{aligned}$$

$F^X(\cdot)$ is a constant elasticity of transformation (CET) function whose form is shown in the upper part of Figure 5. $\eta_{r,g}$ denotes the elasticity of transformation governing the supply of output to regional markets. For both production and supply, sample elasticities are chosen, though estimated or calibrated values may be used (for instance, see Lanz and Rutherford (2016)).

The demand for goods across geographically distinct markets (state, national and foreign) follows Armington (1969) where substitution possibilities depend on the location of production.[16] This is reflected by the following cost minimization problem.

$$\begin{aligned} \min_{m,nd,dd,md} \quad & (1 + t^M_{r,g}) p^{FX} m_{r,g} + p^N_g nd_{r,g} + p^D_{r,g} dd_{r,g} + p^M_{r,m} md_{r,m,g} \\ \text{s.t.} \quad & F^A_{r,g}(m_{r,g}, nd_{r,g}, dd_{r,g}, md_{r,m,g}) = A_{r,g} \end{aligned}$$

The import aggregation function given by F^A_g is described by a nested CES function shown in Figure 6. The total pool of goods is determined by foreign imports, national demand, and state level demand (and margin demands). σ^F is the substitution elasticity governing the trade off between foreign and domestic demand and σ^D denotes the substitution elasticity for intra-national goods demand (between a given state and other states). σ^{MAR} is the substitution elasticity between margin types (trade and transport) and σ^A is the top level elasticity. The latter two are set to zero to reflect an assumption on equal proportions.

Margin demands are determined by inputs supplied by the national and regional markets, which are given by a cost minimization problem. We assume that margins have fixed proportions (Leotief production).

$$\begin{aligned} \min_{nm,dm} \quad & \sum_g \left(p^N_g nm_{r,g,m} + p^D_{r,g} dm_{r,g,m} \right) \\ \text{s.t.} \quad & F^M_{r,m}(nm_{r,g,m}, dm_{r,g,m}) = MS_{r,m} \end{aligned}$$

The demand side of the model is characterized by a regional household representative agent. Optimizing agents are assumed to maximize utility subject to their

---

[15] The description of the canonical model assumes a pooled national market where explicit bilateral trade flows between regions are suppressed. In the energy-economy module discussed below, we show how the model changes when bilateral trade flows are included.

[16] There are alternative ways to specify intra- and international trade. Here, we choose the Armington framework in the canonical model for its widespread use in the literature. In a regional context, added care is needed to capture trade elasticities which may not reflect national level estimates (see Partridge and Rickman (1998)).

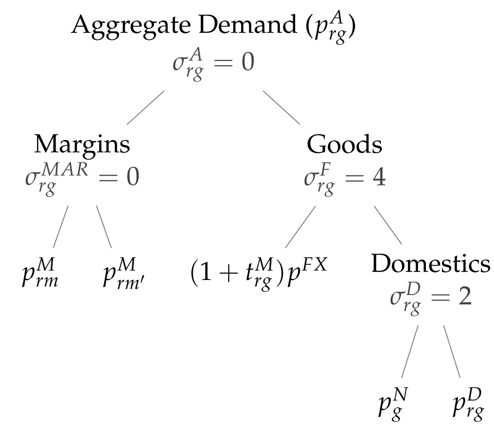

Figure 6. Nested CES import aggregation function

budget constraint. We model demand by assuming Cobb-Douglas preferences between goods (holding fixed government and investment demands).

$$
\begin{aligned}
\max_{cd} \quad & U(cd_{r,g}) \\
\text{s.t.} \quad & RA_r = \sum_g p^Y_{r,g}\bar{yh}_{r,g} + p^L_r \sum_s \bar{ld}_{r,s} + \sum_s p^K_{r,s}\bar{kd}_{r,s} + \bar{bop}_r + \bar{adj}^{hh}_r \\
& + \sum_g \left(t^A_{r,g} A_{r,g} + t^M_{r,g} m_{r,g} \right) - \sum_g p^A_{r,g} \left(\bar{g}_{r,g} + \bar{i}_{r,g} \right)
\end{aligned}
$$

4.2 Equilibrium Conditions

We can alternatively cast the general equilibrium optimization problem as an equilibrium problem in a system of inequalities known as a mixed complementarity problem (MCP). MCP representations of general equilibrium models have been shown to be robust and efficient given the framework's ability to avoid specifying intermediate and definitional variables (Mathiesen, 1985; Rutherford, 1995).

A model equilibrium requires three sets of conditions outlined above: zero excess profits, cleared markets and balanced incomes. The zero profit condition maintains that markets act competitively with free entry and exit. This assumption requires that the price of output (or unit revenue) be less than or equal to the unit cost of inputs, otherwise production is zero. Let $\Pi^Y(p)$ denote a unit profit function for activity Y. The zero profit condition can be written as: $-\Pi^Y(p) \geq 0 \perp Y \geq 0$. In words, if the cost of inputs is greater than the revenue received from outputs, production is zero. Market clearing conditions allow for fluctuating prices to equate supply with demand. Let S denote supply and D denote demand for a good with price p. The associated complementarity condition follows: $S(p) - D(p) \geq 0 \perp p \geq 0$. If supply is greater than demand, arbitrage between producers and consumers force the price to zero. While these conditions are written generally to allow for corner solutions (using weak inequalities and the $\perp$ symbol), the core WiNDC model is formulated more simply as a nonlinear system of equations. Subsequent extensions to the model may warrant explicit representation of complementarities (e.g. imposing carbon abatement targets).

All profit functions are represented as unit functions. We use Shepard's Lemma to generate netput coefficients by differentiating a given profit function with respect to a given price to characterize net supply. Further, reference prices are normalized to unity such that CGE parameters represent quantities (usually they represent value). The respective GAMS code can be found in Appendix C. We also provide MPSGE code that provides concise representation of the equivalent model (Rutherford, 1999).

4.2.1 Zero Profit

We first define intermediate functions representing expressions for equilibrium levels of demands and supplies. The assumed production structure for $Y_{r,s}$ is a nested CES function with Cobb-Douglas technologies for value added. Let the value share of labor relative to total value added be $\alpha^L_{r,s}$ and let $c\bar{v}a_{r,s}$ denote the reference cost of value added.

$$\alpha^L_{r,s} = \frac{\bar{ld}_{r,s}}{\bar{ld}_{r,s} + \bar{kd}_{r,s}} = \frac{\bar{ld}_{r,s}}{c\bar{v}a_{r,s}}$$

The unit cost of value added with Cobb-Douglas technologies in calibrated share form is characterized as follows.[17]

$$C^{VA}_{r,s} = p^{L\ \alpha^L_{r,s}}_r p^{K\ 1-\alpha^L_{r,s}}_{r,s}$$

Given this cost function, we can define the equilibrium labor and capital input demands.

$$LD_{r,s} = c\bar{v}a_{r,s} \frac{\partial C^{VA}_{r,s}}{\partial p^L_r} = \bar{ld}_{r,s} \frac{C^{VA}_{r,s}}{p^L_r}$$

$$KD_{r,s} = c\bar{v}a_{r,s} \frac{\partial C^{VA}_{r,s}}{\partial p^K_{r,s}} = \bar{kd}_{r,s} \frac{C^{VA}_{r,s}}{p^K_{r,s}}$$

The zero profit condition for $Y_{r,s}$ is decomposed into revenue (the value of output) relative to input costs. Input costs are expressed linearly and embed equilibrium intermediary functions.

$$\Pi^Y_{r,s} = \sum_g p^Y_{r,g} \bar{ys}_{r,s,g} - \sum_g p^A_{r,g} \bar{id}_{r,g,s} - p^L_r LD_{r,s} - p^K_r KD_{r,s} = 0 \tag{46}$$

The allocation of output (both sectoral and household) is characterized by a CET function with elasticity of transformation, η_{rg}. Let the value shares of foreign

[17] See Rutherford (2002) for more on calibrated share form equations.

exports, national supply and regional supply respectively be defined as follows.

$$\alpha^X_{r,g} = \frac{\bar{x}_{r,g} - \bar{rx}_{r,g}}{\bar{s}_{r,g}}, \quad \alpha^N_{r,g} = \frac{\bar{xn}_{r,g}}{\bar{s}_{r,s}}, \quad \alpha^D_{r,g} = \frac{\bar{xd}_{r,g}}{\bar{s}_{r,g}}$$

The unit revenue function for output allocation, $X_{r,g}$, is comprised of these three supply markets.

$$R^X_{r,g} = \left(\alpha^X_{r,g} p^{FX\ 1+\eta_{r,g}} + \alpha^N_{r,g} p^{N\ 1+\eta_{r,g}}_{r,g} + \alpha^D_{r,g} p^{D\ 1+\eta_{r,g}}_{r,g} \right)^{1/(1+\eta_{r,g})}$$

Using Shepard's Lemma, we can solve for supply functions for each respective market.

$$S^X_{r,g} = \bar{s}_{r,g} \frac{\partial R^X_{r,g}}{\partial p^{FX}} = (\bar{x}_{r,g} - \bar{rx}_{r,g}) \left(\frac{p^{FX}}{R^X_{r,g}} \right)^{\eta_{r,g}}$$

$$S^N_{r,g} = \bar{s}_{r,g} \frac{\partial R^X_{r,g}}{\partial p^N_g} = \bar{xn}_{r,g} \left(\frac{p^N_g}{R^X_{r,g}} \right)^{\eta_{r,g}}$$

$$S^D_{r,g} = \bar{s}_{r,g} \frac{\partial R^X_{r,g}}{\partial p^D_{r,g}} = \bar{xd}_{r,g} \left(\frac{p^D_{r,g}}{R^X_{r,g}} \right)^{\eta_{r,g}}$$

The zero profit condition for $X_{r,g}$ is comprised of revenues associated with each supply market.

$$\Pi^X_{r,g} = p^{FX} S^X_{r,g} + p^N_g S^N_{r,g} + p^D_{r,g} S^D_{r,g} - p^Y_{r,g} \bar{s}_{r,g} = 0 \tag{47}$$

The total pool of goods representing final demand and intermediate input demand is the sum of demands from the foreign (imports), national and regional markets. The assumed nested CES function in Figure 6 asserts that margins are applied evenly across demand categories. The value shares for the goods nest of the import aggregation function are defined as follows.

$$\theta^N_{r,g} = \frac{\bar{nd}_{r,g}}{\bar{nd}_{r,g} + \bar{dd}_{r,g}}, \quad \theta^M_{r,g} = \frac{(1 + \bar{tm}_{r,g})\bar{m}_{r,g}}{\bar{nd}_{r,g} + \bar{dd}_{r,g} + (1 + \bar{tm}_{r,g})\bar{m}_{r,g}}$$

The unit cost of the lower nest between regional and national demand for good g is represented by a constant elasticity of substitution function.

$$C^{DN}_{r,g} = \left(\theta^N_{r,g} p^{N\ 1-\sigma^D_{r,g}}_g + (1 - \theta^N_{r,g}) p^{d\ 1-\sigma^D_{r,g}}_{r,g} \right)^{1/(1-\sigma^D_{r,g})}$$

The trade off between foreign imports and the domestic good composite is also represented by a CES function. Here, we distinguish $\bar{tm}_{r,g}$ from $t^M_{r,g}$ which are equivalent in the benchmark, to provide notation for possible tax policy scenarios.

$$C^{DM}_{r,g} = \left(\theta^M_{r,g} \left(\frac{p^{FX}(1 + t^M_{r,g})}{(1 + \bar{tm}_{r,g})} \right)^{1-\sigma^F_{r,g}} + (1 - \theta^M_{r,g}) C^{DN\ 1-\sigma^F_{r,g}}_{r,g} \right)^{1/(1-\sigma^F_{r,g})}$$

Input demand functions can be solved for as above. Let $\bar{cdm}_{r,g} = \bar{nd}_{r,g} + \bar{dd}_{r,g} + (1 + \bar{tm}_{r,g})\bar{m}_{r,g}$.

$$D^M_{r,g} = \bar{cdm}_{r,g} \frac{\partial C^{DM}_{r,g}}{\partial p^{FX}} = (1 + \bar{tm}_{r,g})\bar{m}_{r,g} \left(\frac{C^{DM}_{r,g}(1 + \bar{tm}_{r,g})}{p^{FX}(1 + t^m_{r,g})} \right)^{\sigma^F_{r,g}}$$

$$D^N_{r,g} = \bar{cdm}_{r,g} \frac{\partial C^{DM}_{r,g}}{\partial p^N_g} = \bar{xn}_{r,g} \left(\frac{C^{DM}_{r,g}}{C^{DN}_{r,g}} \right)^{\sigma^F_{r,g}} \left(\frac{C^{DN}_{r,g}}{p^N_g} \right)^{\sigma^D_{r,g}}$$

$$D^D_{r,g} = \bar{cdm}_{r,g} \frac{\partial C^{DM}_{r,g}}{\partial p^D_{r,g}} = \bar{xd}_{r,g} \left(\frac{C^{DM}_{r,g}}{C^{DN}_{r,g}} \right)^{\sigma^F_{r,g}} \left(\frac{C^{DN}_{r,g}}{p^D_{r,g}} \right)^{\sigma^D_{r,g}}$$

The zero profit condition for $A_{r,g}$ is composed of the value of demands and margins relative to the output price.

$$\begin{aligned} \Pi^A_{r,g} =& p^A_{r,g}(1 - \bar{ta}_{r,g})\bar{a}_{r,g} + p^{FX}\bar{rx}_{r,g} \\ & - p^{FX} D^M_{r,g} - p^N_{r,g} D^N_{r,g} - p^D_{r,g} D^D_{r,g} - \sum_m p^M_{r,m} \bar{md}_{r,m,g} = 0 \end{aligned} \quad (48)$$

The zero profit condition for margin supply ($MS_{r,m}$) can be formulated explicitly because of the assumed Leontief production structure.

$$\Pi^{MS}_{r,m} = p^M_{r,m} \sum_g \bar{md}_{r,m,g} - \sum_g \left(p^N_g \bar{nm}_{r,g,m} + p^D_{r,g} \bar{dm}_{r,g,m} \right) = 0 \quad (49)$$

Equations (46), (47), (48) and (49) characterize all necessary zero profit conditions in the WiNDC canonical framework.

4.2.2 Market Clearance

A market clearance equation is necessary for every price in the model (except the numeraire according to Walras' Law). In this subsection each condition is represented as: $S(p) - D(p) = 0$. Before itemizing the conditions, we define one additional activity variable, C_r, which represents aggregate household final demand in region r. Assuming Cobb-Douglas preferences for the representative agent and a given level of final consumption, final demands can be expressed by "zero profit" equations. The expenditure function of the representative agent is composed of regional goods (where the distinction between imports and regional production is made in $A_{r,g}$). Let the value shares of consumption be defined using reference demands and $\bar{c}_r$ denote the value of total final demand.

$$\theta^C_{r,g} = \frac{\bar{cd}_{r,g}}{\sum_{g'} \bar{cd}_{r,g'}} = \frac{\bar{cd}_{r,g}}{\bar{c}_r}$$

The unit expenditure function is formulated as the composite unit price of aggregate final demand.

$$p_r^c = \prod_g p_{r,g}^{A\ \theta_{r,g}^C}$$

Input demands are found by differentiating p_r^C with respect to a given goods price, $p_{r,g}^A$.

$$D_{r,g}^C = \bar{c}_r \frac{\partial p_r^C}{\partial p_{r,g}^A} = \bar{cd}_{r,g} \left(\frac{p_r^C}{p_{r,g}^A} \right)$$

The zero profit condition associated with the final demand aggregation, C_r, is written as follows.

$$\Pi_r^C = p_r^C \bar{c}_r - \sum_g p_{r,g}^A D_{r,g}^C = 0 \tag{50}$$

The market clearance condition for $p_{r,g}^A$ is composed of input demands by agents and sectoral production.

$$A_{r,g} \bar{a}_{r,g} - \bar{g}_{r,g} - \bar{i}_{r,g} - C_r D_{r,g}^C - \sum_s Y_{r,s} \bar{id}_{r,g,s} = 0 \tag{51}$$

The output market with price $p_{r,g}^Y$ is supplied by sectoral and household production and demanded by the allocation market.

$$\sum_s Y_{r,s} \bar{ys}_{r,s,g} + \bar{yh}_{r,g} - X_{r,g} \bar{s}_{r,g} = 0 \tag{52}$$

The regional level of supply must be greater than or equal to the amount regionally demanded plus margin formulation in region r for good g at price $p_{r,g}^D$.

$$X_{r,g} S_{r,g}^D - A_{r,g} D_{r,g}^D - \sum_m MS_{r,m} \bar{dm}_{r,g,m} = 0 \tag{53}$$

Similarly, by summing across regions to create a pooled national market, the level of national supply across regions must satisfy the total domestic demand for both goods and margins at price p_g^N.

$$\sum_r \left(X_{r,g} S_{r,g}^N - A_{r,g} D_{r,g}^N - \sum_m MS_{r,m} \bar{nm}_{r,g,m} \right) = 0 \tag{54}$$

With price, p_r^L, we assume labor to be freely mobile across sectors, but fixed to a region.

$$\sum_s \left(\bar{ld}_{r,s} - Y_{r,s} LD_{r,s} \right) = 0 \tag{55}$$

Capital is assumed to be sector and region specific ($p^K_{r,s}$) and therefore the market clearing condition for capital must hold for each region-sector pairing.

$$\bar{kd}_{r,s} - Y_{r,s} KD_{r,s} = 0 \tag{56}$$

The market for margins must clear for each region and margin type at price $p^M_{r,m}$. The market clearance condition requires that margins supplied through the regional and national market must be greater than or equal to the total level of margin demand in the absorption goods market.

$$MS_{r,m} \sum_g \bar{md}_{r,m,g} - \sum_g A_{r,g} \bar{md}_{r,m,g} = 0 \tag{57}$$

The intermediary zero profit condition on C_r allows us to concisely represent the market for aggregate final demand. As p^C_r denotes the composite price of a unit of aggregate demand, the total quantity demanded is the composite price divided into total household income RA_r.

$$C_r \bar{c}_r - \frac{RA_r}{p^C_r} = 0 \tag{58}$$

The price of foreign exchange (p^{FX}) is determined by the difference between total imports and exports net of re-exports and reference balance of payments.

$$\sum_r \bar{bop}_r + \sum_{r,g} \left(X_{r,g} S^X_{r,g} + A_{r,g} \left(\bar{rx}_{r,g} - D^M_{r,g} \right) \right) = 0 \tag{59}$$

Equations (51) - (59) describe the full set of market clearing conditions needed for specifying the WiNDC model.

4.2.3 Income Balance

The final equilibrium condition requires that expenditures do not exceed income levels. This condition is reflected in the following equation which defines the the income level for the representative agent and also determines the price p^C_r. Note that we hold fixed government and investment demands and allow tax revenue to accrue to the representative household.

$$\begin{aligned} RA_r = & \sum_g p^Y_{r,g} \bar{yh}_{r,g} + p^{FX} \left(\bar{bop}_r + \bar{adj}^{hh}_r \right) + p^L_r \sum_s \bar{ld}_{r,s} + \sum_s p^K_{r,s} \bar{kd}_{r,s} \\ & + \sum_g A_{r,g} \left(p^{FX} t^M_{r,g} D^M_{r,g} + p^A_{r,g} t^A_{r,g} \bar{a}_{r,g} \right) - \sum_g p^A_{r,g} \left(\bar{g}_{r,g} + \bar{i}_{r,g} \right) \end{aligned} \tag{60}$$

With fixed government and investment expenditures, equation (60) represents the needed income balance constraint for specifying an equilibrium.

5. An energy-economy model

In the last two sections we have described the construction of the *core* WiNDC dataset and modeling environment. In this section, we introduce the energy-environment module. WiNDC modules are based on the core dataset and modeling environment and incorporate additional data and modeling assumptions that are specific to certain analyses. The energy-environment module generates a data instance by recalibrating the core database using information on regional energy markets from the State Energy Data System (SEDS). SEDS is a product of the Energy Information Administration that accounts for state level differences in prices and physical quantities of energy resources in supply and demand by sectors and final demand. SEDS data is available for the years 1963 to 2016. We focus on data for 2016 to simulate various state level climate policies.

We proxy for markups in energy markets through margins. The SEDS data provides prices for demands. We distinguish between the supply and demand prices for energy and electricity by assuming that the supply price is the minimum price across regions and demanding sectors. Given a lack of data for crude oil prices, its supply price is assumed to be half of the corresponding price for refined oil. The difference in the demand and supply prices for energy characterizes markups between wholesale and final demand across aggregated categories (e.g. industrial, residential). New margin totals are shared out to input output sectors using existing margins in the input output data. In particular, this distinction between supply and demand prices leads to a restructuring of the electricity generating sector. The reference BEA data does not report any trade or transport margin demand by the electricity sector, but rather embeds these costs into the overall production value. Here, we impose the calculated margins and adjust the production schedule.

We treat energy input demands in a similar way. SEDS reports energy input demands by aggregate sectors (industry, commercial, residential, transportation, electricity generation and oil refining), therefore we share out such demands given information from the core input output table, adjusting the scale of input demands rather than the regional and sectoral composition of use. Energy supplies are added explicitly given price and quantity data to the corresponding sectors. The data also allow us to keep track of net interstate flows of electricity to ensure that national demand of electricity relative to national supply in the economic accounts follow similar magnitudes. Notably, converting demand and supply of energy into value terms requires converting energy quantities from BTUs (British Thermal Unit) to KWHs (Kilowatt Hours). For this conversion we impose heat rates which provide a conversion scaler by technology and year.[18] We also translate energy quantities to emissions through carbon dioxide content coefficients and verify

[18] Data is taken from the U.S. Energy Information Administration at: https://www.eia.gov/electricity/annual/html/epa_08_01.html.

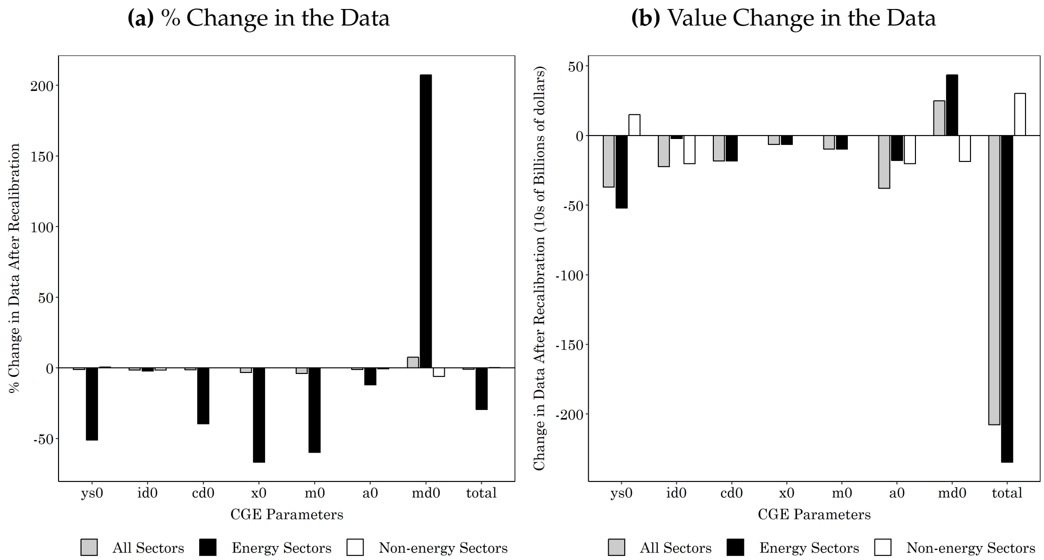

Figure 7. Change in data due to re-calibration

Source: Authors calculations.

their consistency with reports from the U.S. Environmental Protection Agency.[19]

The final output of this sub-routine is re-calibrated data for a single year. Figure 7 describes the both the percent and value change in a subset of CGE parameters following the recalibration routine for 2016 data. The percent change in the data after recalibration is large for energy sectors (electricity and primary energy sectors) relative to non-energy sectors. This difference stems mainly from the reorganization of the electricity generation sector. Electricity distribution and transmission estimates are shifted towards margins (hence the large increase in the value of data). However, as is evident by the percent change in select CGE parameters for all sectors, energy sectors account for a relatively small share of the economy. This point is further illustrated in Figure 7b which reports the total value change in the data following the recalibration routine.

5.1 *Sectoral aggregation: embodied carbon*

We aggregate sectors according to embodied carbon to reduce the dimensionality of the dataset in the energy-economy model. Embodied carbon is both the

[19] In practice, raw SEDS data are converted into a GAMS readable format and aggregated to match the sectoral and region schemes in the climate policy analysis. Using this data, we separate the natural gas and crude oil extraction sector given the relative production value of crude oil to natural gas by year and region to generate shares, we enforce state level energy supplies, demands and trade and adjust the remaining accounts with optimization based matrix balancing techniques to accommodate the new economic data.

amount of carbon emitted directly through production or indirectly through the supply chain of using carbon intensive goods as inputs or in final demand. We calculate the level of embodied carbon in the output of each sector-region pairing by solving a system of linear equations. Let $e^Y_{r,s}$ denote the embodied carbon in output of sector s in region r, $e^P_{r,g}$ be the embodied carbon in domestic goods and $e^{PM}_{r,g}$ the embodied carbon in imports of good g into region r. Further, let $e^{PA}_{r,g}$ denote the embodied carbon in the Armington supply of goods, e^{PN}_{g} be the embodied carbon in nationally produced goods and $e^{PMRG}_{r,g}$ be the embodied carbon in margin demand. Given our equilibrium accounting identities, we can formulate the following system of linear equations to solve for the embodied carbon coefficients. Let $\bar{co2}_{r,g,s}$ be the level of direct CO2 emissions from sector s in region r for using input g. The total carbon content in sectoral output is characterized by both direct emissions and carbon intensive inputs.

$$e^Y_{r,s} \sum_g \bar{ys}_{r,s,g} = \sum_g \bar{co2}_{r,g,s} + \sum_g e^{PA}_{r,g} \bar{id}_{r,g,s}$$

As production includes byproducts in the WiNDC framework (a given sector can have multiple types of output), we translate the carbon content of sectoral output to the carbon content of a given goods state level supply.

$$e^P_{r,g} \sum_s \bar{ys}_{r,s,g} = \sum_s e^Y_{r,s} \bar{ys}_{r,s,g}$$

We assume that imports have twice the carbon content of locally produced goods.

$$e^{PM}_{r,g} = 2 e^P_{r,g}$$

In a pooled national market, the carbon content of a given good is composed of a weighted average of all regions supplying the pooled market.

$$e^{PN}_g \sum_r \bar{xn}_{r,g} = \sum_r e^P_{r,g} \bar{xn}_{r,g}$$

The carbon content of margins are supplied through the national and state level markets.

$$e^{PMRG}_{r,m} \sum_g \bar{md}_{r,m,g} = \sum_g \left(e^{PN}_g \bar{nm}_{r,g,m} + e^P_{r,g} \bar{dm}_{r,g,m} \right)$$

Finally, the embodied carbon in the Armington supply of a good g into region r to be used as intermediate input or final demand is composed of the carbon content from regional and national demand, imports and margins.

$$e^{PA}_{r,g} \left(\bar{a}_{r,g} + \bar{rx}_{r,g} \right) = e^P_{r,g} \bar{dd}_{r,g} + e^{PN}_g \bar{nd}_{r,g} + e^{PM}_{r,g} \bar{m}_{r,g} + \sum_m e^{PMRG}_{r,m} \bar{md}_{r,m,g}$$

We solve this problem for embodied carbon coefficients using linear programming. Averaging across the United States, the top 15 most carbon intensive sectors are included in Figure 8 reported in kilograms per dollar of CO2 for 2016. The most carbon intensive sectors are electricity, petroleum products, oil refining, transporta-

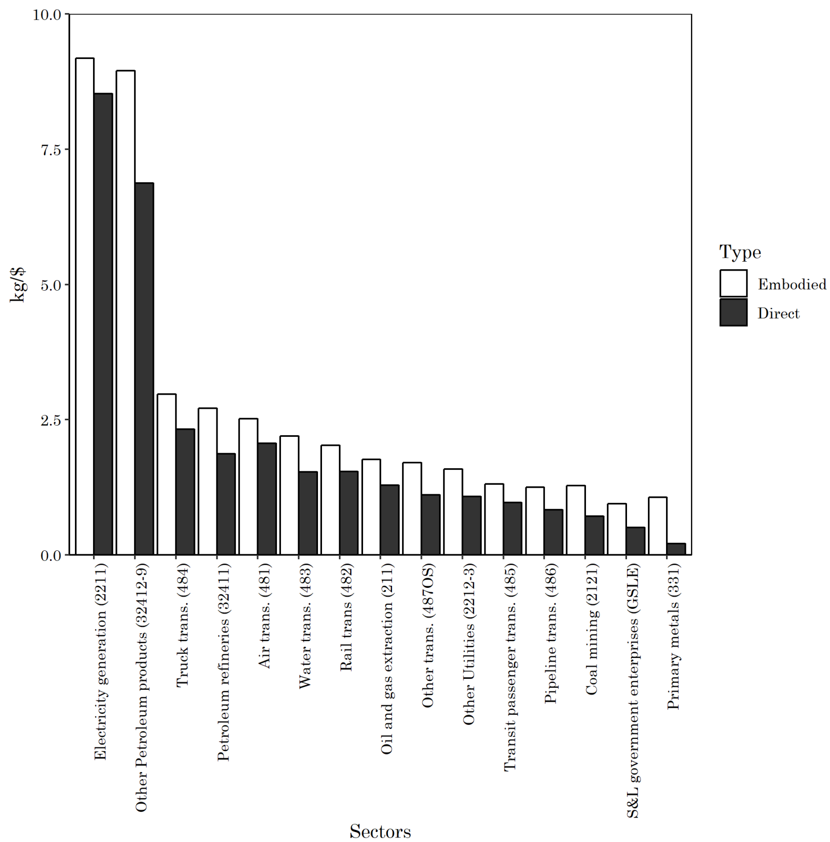

Figure 8. Top 15 most carbon intensive sectors in the United States (2016)

Source: Authors calculations.

tion, other utilities and metal processing. These estimates are comparable to those reported by Böhringer, Carbone, and Rutherford (2018) for the United States.

Each state has a different profile of carbon intensity by sector depending on technologies (direct emissions) and the regional configuration of where inputs are sourced (indirect emissions). For comparison, Figure 9 reports a ranking of US states by carbon intensity including both direct and indirect emissions for producers of electricity and refined petroleum. Emissions from the electricity sector are largely produced directly from combustion of fossil based material inputs and are largest for states with high concentrations of coal fired power plants. In comparison, not all states produce refined petroleum but for those that do, carbon intensities are split between indirect and direct emissions.

Sources of indirect emissions can be summarized by the components of e^{PA}_{rg}. Figure 10 reports the difference between the electricity and oil refinery goods by state for components of the Armington composite good. The Armington composite describes the total level of material inputs available for use in final demand or as inter-

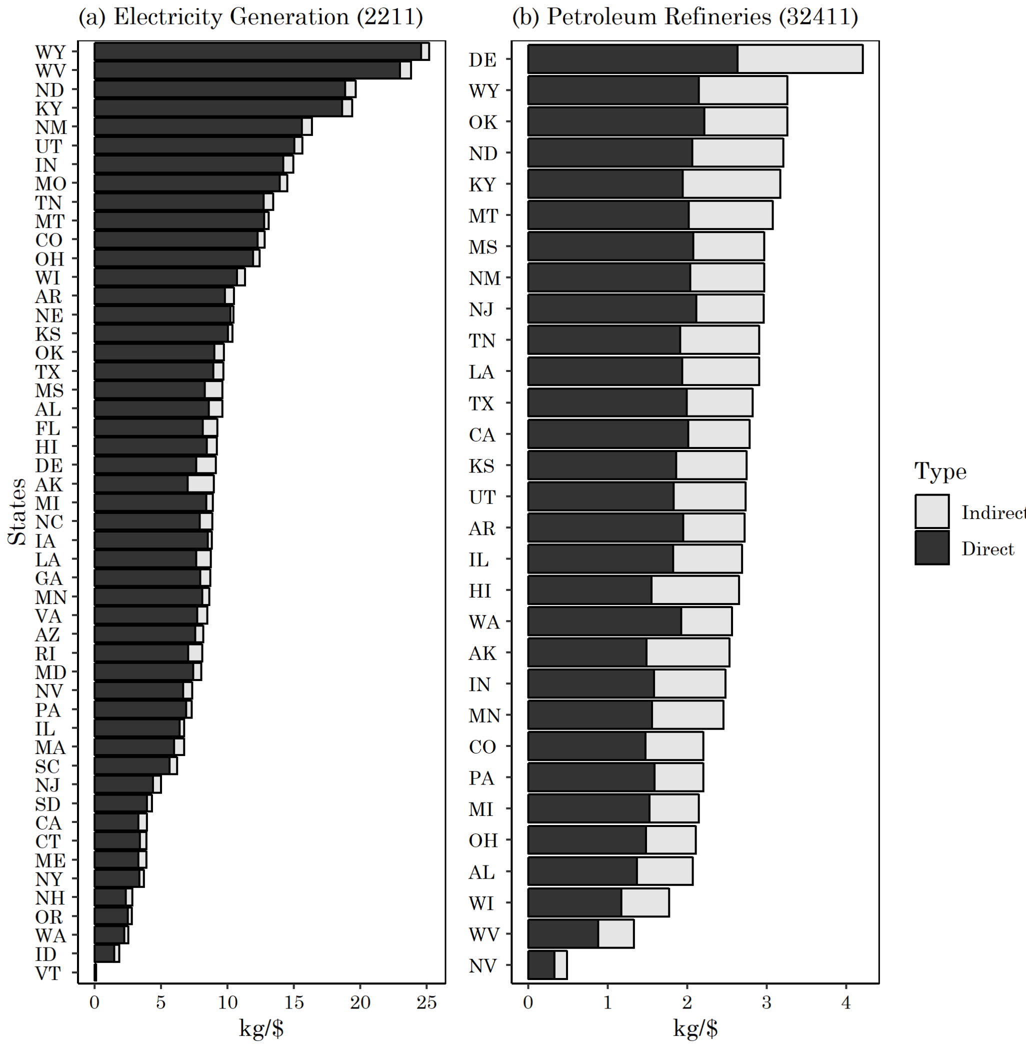

Figure 9. The composition of direct and indirect embodied carbon in the electricity and refined oil production sectors (2016)

Source: Authors calculations.

mediate inputs in production. This calculation decomposes upstream emissions by source: state level production, imports from the national and international markets, and margin demand for trade and transport. Though small, indirect emissions due to electricity production are largely produced in the same state (given assumptions in the data on regional purchase coefficients). The sources for embodied emissions in refined petroleum are characterized mainly through transport margins and imports from the national market. For states that do not have any primary petroleum production (those not included in Figure 9), the state component of indirect emissions is zero. In these states, refined petroleum demanded by consumers or used

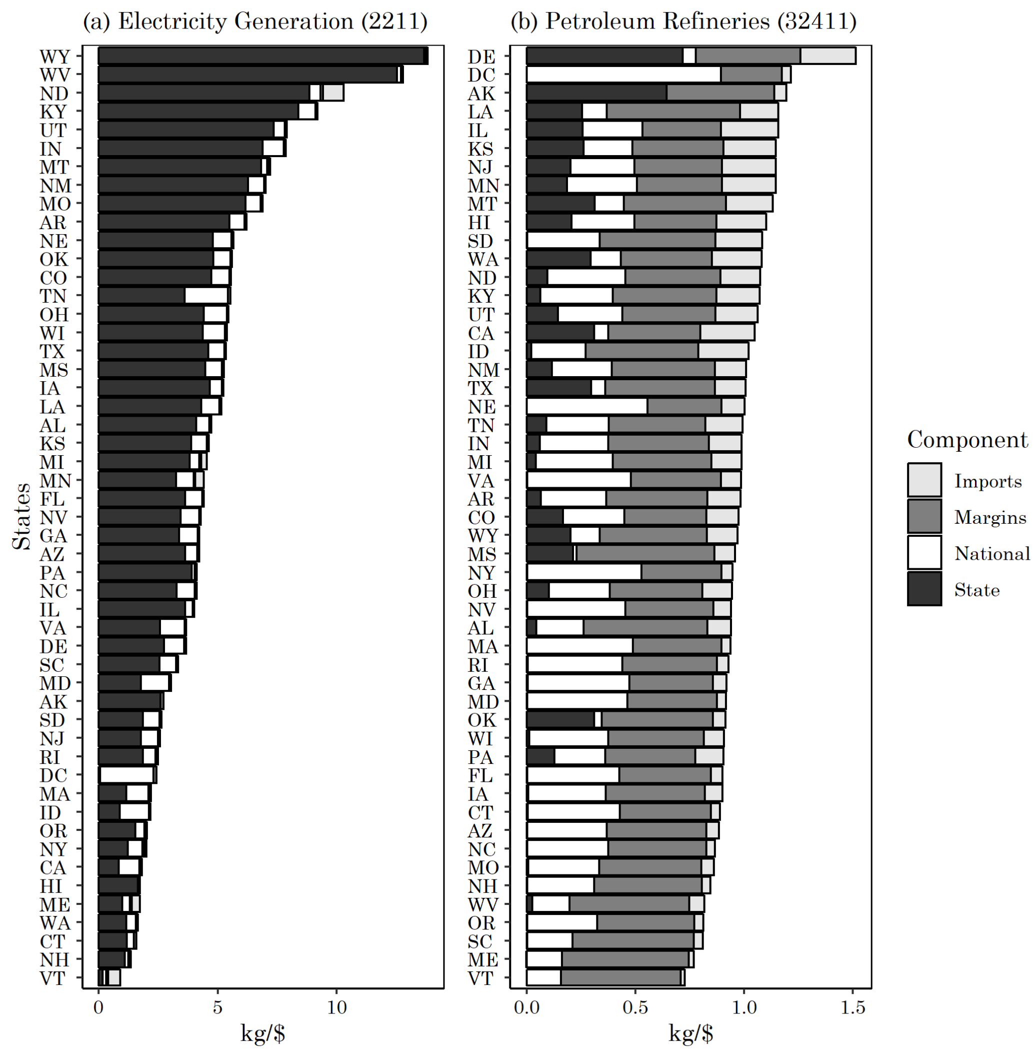

Figure 10. The composition of indirect embodied carbon in the electricity and refined oil Armington composite goods (2016)

Source: Authors calculations.

as an intermediate input comes from other states or countries.

The sectoral aggregation used for this module reflects these calculations and is shown in Table 7. Disaggregate sectors are those with high levels of carbon emissions or important features in the creation of emissions: electricity generation, primary energies, and transportation. Other energy/emission intensive sectors are defined as those with embodied carbon greater than .5 kilograms per dollar and are aggregated into *eint*. The remaining aggregate sectors are other manufacturing,

Table 7. Sectoral aggregation

Symbol	Description
oil	Petroleum refineries
cru	Crude oil extraction
gas	Natural gas extraction
col	Coal mining
ele	Electric power generation, transmission, and distribution
trn	Transportation
con	Construction
eint	Energy/Emission intensive sectors (embodied carbon ¿ .5 kg per $)
omnf	Other manufacturing sectors
osrv	Other services
roe	Rest of the economy

Source: Authors' own aggregation.

services and rest of economy (government sectors).[20]

5.2 Application: state level climate policy

In the United States, disinterest for comprehensive climate policy has prompted some states and cities to engage in climate efforts individually or through collective efforts. Even pre-Paris Agreement, state action aimed at curbing carbon emissions existed. The Regional Greenhouse Gas Initiative (RGGI) encompasses a collection of northeastern states with the intent of reducing carbon emissions from the electricity sector. It is the first instance of a market based cap and trade system for reducing carbon emissions for fossil fuel generating plants in the United States. California's AB-32 is a more comprehensive program seeking to reduce economy wide emissions through a combination of policy frameworks (e.g. cap and trade, fuel standards, renewable energy standards). There are also historical records of proposed legislation (not yet implemented) for a comprehensive state level carbon tax in Massachusetts, New York, Oregon, Rhode Island, Vermont, and Washington.

In some states without a history of proposed climate policy, a collection of state governors have committed to The US Climate Alliance after the United States exited from the Paris Agreement.[21] The US Climate Alliance is committed to the goals of the Paris Agreement of reducing greenhouse gas emissions by 26-28% below 2005 levels by 2025. In states without state level elected officials interested in climate policy, many city mayors have joined Climate Mayors seeking to reduce emissions on a smaller scale.[22] The states New York, Hawaii, California, Illinois, Texas, Arizona, North Carolina, Colorado, District of Columbia, Tennessee, Oregon, New Mexico, Alaska have over 20% of their total state population living in cities with mayors committed to the Paris Agreement goals.[23] The report by Bau-

[20] The energy-economy aggregation scheme required separating coal mining, electric utilities, oil refineries, crude oil extraction and natural gas extraction from their respective aggregated WiNDC sectoral scheme.
[21] See: https://www.usclimatealliance.org/
[22] See: http://climatemayors.org/
[23] Own calculations using population data from the Census Bureau.

man and Komanoff (2017) takes into consideration these facts and other information on social, legal and economic circumstances in each state and offers an analysis on the potential for a state level carbon tax. The authors find that 14 states have the potential for a carbon tax, 11 states have challenging legal or ideological commitments for action, and the rest have very challenging environments for social, legal and/or economic reasons.

When one state introduces mitigation measures, the resulting policies make energy-intensive goods produced in this region more expensive than energy-intensive goods produced in unregulated regions. Production of energy-intensive goods in unregulated states may thereby substitute for the goods produced in regulated regions. This is known as carbon leakage (Felder and Rutherford, 1993). Leakage is a challenging issue in a subnational setting because (by constitutional mandate) states are unable to impose border sanctions. The level of carbon leakage will determine the effectiveness of reducing emissions country-wide. Caron et al. (2015) study the leakage implications of California's cap and trade program using IMPLAN and GTAP (Global Trade and Analysis Project) data. Bilateral trade flows between states are taken from the gravity model of trade of IMPLAN, replacing state level electricity trade with data from the National Renewable Energy Laboratory's ReEDS model (Short et al., 2009). Without any measure of border adjustments, the authors calculate a 45% leakage rate with an imposed carbon price of \$15 per ton of CO2. Similarly, Sue Wing and Kolodziej (2008) model the subnational leakage effects of the RGGI market using a pooled national market for state bilateral trade. They find that that without the imposition of state level border adjustments, calculated leakage rates range from 49-57%.

The ability of firms and agents to substitute goods produced in regulated regions depends, in part, on assumptions made on intra-national trade and substitution possibilities in the production function. We make structural adjustments to the dataset and model to study the sensitivity of model results to assumptions on these margins. We note that there are additional complicating factors not covered in this analysis like overlapping regulations, (e.g. Böhringer and Behrens (2015)), comprehensive treatment of electricity markets or differentiated policy design. For instance, while California and RGGI states may have the potential to adopt some type of additional climate policy, overlapping emissions regulations will impact the performance of the existing program.[24] Here we seek to understand how sensitive country wide emissions reductions from caps on state level economy wide carbon emissions are to a variety of data and model related assumptions. We leave the complexities mentioned above for future research.

[24] For instance, Akin-Olcum et al. (2019) show that if New York imposes an additional price adder on top of the RGGI permit price for its electricity generators, the permit price is driven downward which creates a wedge in welfare between New York households and other RGGI states.

5.2.1 Gravity model of trade

The core WiNDC dataset and model feature a pooled national market to proxy for intra-national trade. Bilateral trade flows between US states can alternatively be modeled using a gravity model. The gravity model, a framework traditionally used to predict foreign trade flows (e.g. Sapir (1981), Abrams et al. (1980)), asserts that the trade in value terms from region i to region j depends on economic forces in both origin and destination nodes, and on factors which may aid or restrict the flow of goods from origin to destination (Bergstrand, 1985).[25] We compare the results of the model with a pooled national market with the results of the gravity model to assess the importance of the pooled national market assumption.

The specification of the gravity model used here relates bilateral trade flows (Y_{ij}) between regions i and j to regional gross product attributed to a given good (both GDP_i and GDP_j), the distance between regions ($Dist_{ij}$), and additional impedance factors between regions i and j (generally written as A_{ij}^f for factor f). We specify the model with a multiplicative error term. Note that the following specification provides a cross sectional approach for estimating trade elasticities for a given sector.

$$Y_{ij} = a_0 \left(GDP_i\right)^{\beta_1} \left(GDP_j\right)^{\beta_2} \left(Dist_{ij}\right)^{\beta_3} \left(\prod_f A_{ij}^{f\ \beta_f}\right) u_{ij}$$

Log-linearizing the model yields an additive expression. We use OLS to estimate the model where $\beta_0 = \ln a_0$, $\epsilon_{ij} = \ln u_{ij}$ and X_{ij}^f denotes additional control variables. X_{ij}^f contains variables for regional contiguity and same dominant language in origin and destination regions. Note that this model is estimated separately for all sectors in the dataset.

$$lnY_{ij} = \beta_0 + \beta_1 \ln(GDP_i) + \beta_2 \ln(GDP_j) + \beta_3 \ln(Dist_{ij}) + \sum_f \beta_f X_{ij}^f + \epsilon_{ij} \qquad (61)$$

We identify the elasticities using D-Level input output data from Statistics Canada for 2014 and use the estimated Canadian elasticities to generate a set of predicted trade levels for the United States. The D-Level input output dataset provides bilateral trade between all Canadian provinces for 230 sectors (not including fictive industries). Lacking a panel dataset, we obtain more explanatory power by running the model for aggregated WiNDC sectors in the energy-economy aggregation

[25] Notably, this is not a paper asserting the correctness of econometric approaches (e.g. Mátyás (1997), Egger (2000)) or the theoretical underpinnings of the gravity model (e.g. Balistreri and Hillberry (2006), Anderson and Van Wincoop (2003), Anderson and Yotov (2010)). Rather, we seek to provide *some* type of empirically estimated measure of trade with available data which can be reconciled within the model, due to the lack of subnational trade metrics reported in the United States.

treating trade between regions for disaggregate sectors in the D-Level tables as separate observations. Distance in kilometers (as the crow flies) between provinces is taken from Anderson and Van Wincoop (2003). Table 8 provides our estimation results. In each case, the model explains the variation in bilateral trade in Canada reasonably well. Elasticities of GDP in both origin and destination regions are statistically significant and positive across sectors. The distance elasticity is unambiguously negative, and larger in absolute value for service sectors and goods not easily traded.

Table 8. Gravity estimates for energy-economy sectors

	(1) *oil*	(2) *cru*	(3) *gas*	(4) *col*	(5) *ele*	(6) *trn*	(7) *con*	(8) *eint*	(9) *omnf*	(10) *osrv*	(11) *roe*
lnFromGDP	0.422***	0.311***	0.311***	0.402***	0.320***	0.445***	0.207***	0.369***	0.356***	0.447***	0.221***
	(0.0594)	(0.0404)	(0.0404)	(0.0861)	(0.106)	(0.0347)	(0.0713)	(0.0325)	(0.0363)	(0.0460)	(0.0602)
lnToGDP	0.166***	0.189***	0.189***	0.221***	0.301***	0.204***	0.207***	0.147***	0.179***	0.226***	-0.0140
	(0.0478)	(0.0336)	(0.0336)	(0.0663)	(0.106)	(0.0341)	(0.0713)	(0.0277)	(0.0351)	(0.0428)	(0.0598)
lnDist	-1.488***	-1.110***	-1.110***	-1.134***	-1.204***	-1.039***	-1.771***	-0.876***	-0.836***	-1.224***	-1.406***
	(0.153)	(0.182)	(0.182)	(0.278)	(0.191)	(0.125)	(0.254)	(0.133)	(0.135)	(0.147)	(0.198)
Contiguity	0.414	0.234	0.234	-0.892*	1.360***	0.282	-0.960*	0.429	0.294	0.0690	0.130
	(0.467)	(0.380)	(0.380)	(0.500)	(0.428)	(0.299)	(0.489)	(0.285)	(0.277)	(0.324)	(0.388)
Language	0.526*	-1.060***	-1.060***	-0.571*	0.518*	0.0162	0.816**	0.0879	0.277	0.115	0.0495
	(0.295)	(0.274)	(0.274)	(0.328)	(0.270)	(0.184)	(0.316)	(0.177)	(0.169)	(0.209)	(0.269)
Constant	4.748***	2.130	2.130	3.240	-0.326	1.614	4.313**	0.0978	-0.450	2.741**	3.274**
	(1.205)	(1.545)	(1.545)	(2.614)	(1.451)	(1.002)	(2.010)	(1.105)	(1.147)	(1.186)	(1.560)
Observations	600	800	800	100	200	2400	2000	20900	4700	12600	4100
R2	0.506	0.359	0.359	0.457	0.513	0.448	0.554	0.415	0.390	0.450	0.346

Notes: Standard errors, clustered by origin destination pairs, are in parentheses with * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Source: Authors calculations.

We use the elasticities to generate a set of bilateral trade flows between states in the United States. In this illustrative calculation we omit uncertainty in parameter estimates. Using uncertainty in parameter estimates could add a further measure of sensitivity to final results. We fit a bilateral trade matrix by using regional sectoral GDP directly from WiNDC for 2016 and distance between states as calculated with GIS shapefiles of population weighted centroids. Core accounts are reassigned given these fitted values. For instance, this includes state level demands and supplies ($\bar{dd}_{r,g}$, $\bar{xd}_{r,g}$, and $\bar{dm}_{r,g,m}$) and national market demands and supplies ($\bar{nd}_{r,g}$, $\bar{xn}_{r,g}$, $\bar{nm}_{r,g,m}$) which were initially calculated using regional purchase coefficients based on the Commodity Flow Survey. Bilateral trade flows are therefore estimated such that totals are maintained from the pooled national market framework. Let $MRT_{r,rr,g}$ characterize a variable for multi-regional trade. We estimate trade flows which satisfy the following constraints by penalizing deviations from fitted values.

$$\sum_{rr} MRT_{r,rr,g} = \bar{xn}_{r,g}$$

$$\sum_{rr} MRT_{rr,r,g} = \bar{nd}_{r,g} + \sum_{m} \bar{nm}_{r,g,m}$$

Notably, the model design must change to accommodate bilateral trade flows as a pooled national market is no longer needed to fully represent the economic system. The total supply of goods from sectoral and household production is allocated to either the foreign market or the local market. The new level of local supply is a gross value composed of both allocated goods previously directed to the national market and those destined for the local market.[26] The demand of goods from other regions, $p^D_{r',g}$ replaces the p^N_g arm of Figure 6.

5.2.2 KLEM production structure and government

We also consider an alternative production structure that modifies the canonical form by embedding energy based substitutions using a "KLEM" (capital, labor, energy and materials) production function. Figure 11 describes this production structure. In this production structure non-energy material inputs may be substituted with energy, see value added composite ($\sigma^Y = 0.25$). We assume that energy is may be substituted with labor and capital according to the elasticity of substitution, σ^{KLE}. σ^{KL} characterizes the trade-off between labor and capital, as before. Energy materials (coal, natural gas, refined oil and crude oil) may be substituted with electricity according to σ^E and CO2 (with shadow price p^{CO2}_{rs}) must be used in fixed proportions with energy material input demands ($\sigma^{FE} = 0$).[27]

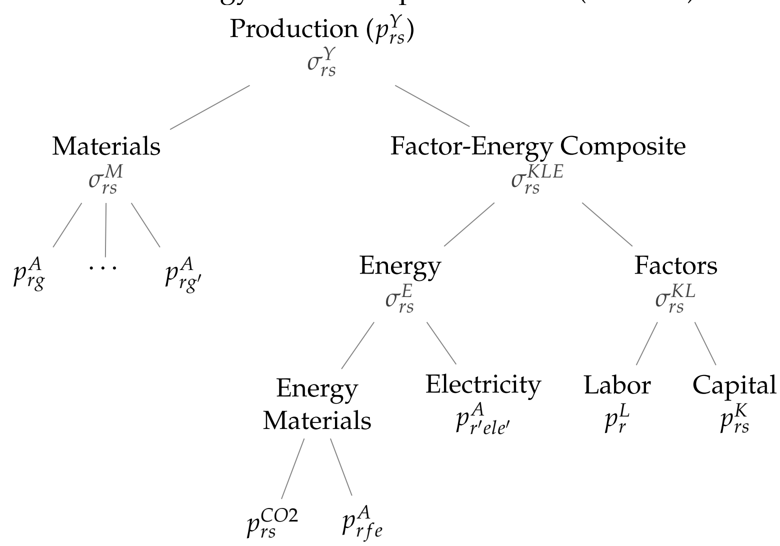

Figure 11. KLEM based production structure

Note that our simulations also feature a separate government agent (still holding investment fixed). The government accrues revenues through taxes and transfers. The core WiNDC build lacks the "fourth quadrant" of the social accounting

[26] Let $\hat{xd}_{rg}$ be the new level of local supply, then: $\hat{xd}_{rg} = \bar{xd}_{rg} + \bar{xn}_{rg}$.
[27] We set $\sigma^{KLE} = 0.25$, $\sigma^{KL} = 0.25$, and $\sigma^E = 0.5$.

Table 9. Policy configurations

Name	Description	Included States
CA	California	CA
RGGI	Regional Greenhouse Gas Initiative States	CT, DE, MA, MD, ME, NH, NY, RI, VT
CA-RGGI	California and RGGI States	CA, CT, DE, MA, MD, ME, NH, NY, RI, VT
History	States with a history of attempted climate action	CA, CT, DE, MA, MD, ME, NH, NY, RI, VT, WA, OR
State Alliance	States with attempted past action and those in the State Alliance	CA, CT, DE, MA, MD, ME, NH, NY, RI, VT, WA, OR, CO, HI, IL, MI, MN, NM, NJ, NC, VA, WI
Carbon Center	States with attempted past action those in the State Alliance, or those deemed with some potential or challenging per the Carbon Tax Center's report	CA, CT, DE, MA, MD, ME, NH, NY, RI, VT, WA, OR, CO, HI, IL, MI, MN, NM, NJ, NC, VA, WI, DC, FL, NV, AR, SC
Climate Mayor	States with attempted past action, in the State Alliance, in the Carbon Tax Center report, or have at least 20% of their population in cities with mayors joining Climate Mayors	CA, CT, DE, MA, MD, ME, NH, NY, RI, VT, WA, OR, CO, HI, IL, MI, MN, NM, NJ, NC, VA, WI, DC, FL, NV, AR, SC, TX, AZ, TN, AK

Source: Authors' simulation scenarios.

matrix and data on transfers between government and households. We use aggregate totals calculated through income balance constraints and impose an equal yield constraint on the government for modeling lump sum payments due to additional permit revenues.

5.2.3 Policy Analysis

Subnational climate policies can achieve multiple objectives. The extent of resulting reductions of national level emissions depends on how much of the reduction in pollution in the policy state(s) is offset by increases elsewhere because of relative prices. In this section, we assess leakage rates due to a 20% decrease in carbon emissions for different configurations of states. Table 9 describes our simulation scenarios. The configuration of states are additive with exception to California or RGGI states. States are included based on historical attempts or a current (partial) willingness to engage in efforts for some type of state level climate policy. The final simulation scenario (*Climate Mayors*) seeks to understand the impacts of city level policies (proxied by state level reductions). In the included states more than 20% of the populations live in cities with mayors that are affiliated with Climate Mayors.

There are three main sensitivity parameters in our model: trade flows, carbon permit trade, and the structure of production. Trade flows are characterized either by explicit bilateral trade flows for each sector and between each region by the gravity estimation routine or in a pooled national market described in the canonical framework. Explicit representation of bilateral trade allows us to constrain inter-regional trade between "likely" trading partners relative to a pooled market. Carbon permits are assumed to be tradable across sectors. In addition, we allow permits to be either tradable or fixed to states imposing the carbon limit to assess the importance of state coalitions and mimic differences between historical markets (AB-32 vs. RGGI). In both cases, permit trade will equalize permit prices across affected regions and/or sectors. Finally, we report result sensitivity to the assumed

Table 10. Carbon emissions and leakage rates: gravity trade and KLEM production structure (%)

		CA		RGGI		CA-RGGI		History		State Alliance		Carbon Center		Climate Mayors	
		Trade	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*
State	*Alaska*	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.3	1.1	0.9	1.4	1.2	-22.2	-20.0
Emissions	*Alabama*	0.9	0.9	1.3	1.3	2.3	2.3	2.7	2.6	6.4	6.2	8.5	8.3	11.5	11.4
% Change	*Arkansas*	0.8	0.8	1.1	1.1	2.0	1.9	2.3	2.2	5.7	5.4	-29.7	-20.0	-27.5	-20.0
	Arizona	1.0	1.0	0.9	0.9	1.9	1.9	2.3	2.3	5.0	4.9	6.4	6.3	-24.2	-20.0
	California	-20.0	-20.0	0.5	0.5	-18.0	-20.0	-18.2	-20.0	-13.0	-20.0	-12.5	-20.0	-11.8	-20.0
	Colorado	0.7	0.7	0.8	0.8	1.6	1.6	1.9	1.8	-31.0	-20.0	-29.5	-20.0	-27.6	-20.0
	Connecticut	0.6	0.6	-17.1	-20.0	-18.7	-20.0	-19.0	-20.0	-13.4	-20.0	-12.8	-20.0	-12.3	-20.0
	D.C.	0.6	0.6	0.5	0.5	1.2	1.2	1.4	1.4	2.3	2.5	-11.0	-20.0	-10.8	-20.0
	Delaware	0.8	0.8	-30.0	-20.0	-33.0	-20.0	-33.6	-20.0	-23.6	-20.0	-22.7	-20.0	-21.9	-20.0
	Florida	0.8	0.8	1.0	1.0	1.9	1.9	2.2	2.2	5.0	4.9	-23.7	-20.0	-21.9	-20.0
	Georgia	0.7	0.7	0.9	0.9	1.7	1.6	1.9	1.9	4.6	4.4	6.1	5.9	8.3	8.2
	Hawaii	1.1	1.1	0.9	0.9	2.0	2.0	2.4	2.4	-35.4	-20.0	-30.8	-20.0	-26.2	-20.0
	Iowa	0.6	0.6	0.8	0.8	1.5	1.4	1.7	1.7	4.4	4.2	5.5	5.4	7.6	7.6
	Idaho	0.7	0.7	0.6	0.6	1.3	1.3	1.6	1.6	2.5	2.7	3.2	3.4	4.1	4.5
	Illinois	0.6	0.6	0.7	0.7	1.3	1.3	1.5	1.5	-22.1	-20.0	-21.4	-20.0	-20.5	-20.0
	Indiana	0.6	0.6	1.0	0.9	1.6	1.6	1.9	1.8	5.4	5.0	6.8	6.5	9.4	9.1
	Kansas	0.7	0.7	0.8	0.8	1.5	1.5	1.8	1.8	4.7	4.5	6.0	5.8	8.3	8.2
	Kentucky	0.7	0.7	1.2	1.2	2.0	1.9	2.3	2.2	6.4	6.0	8.2	7.8	11.1	10.8
	Louisiana	0.3	0.3	0.3	0.3	0.6	0.6	0.7	0.7	1.7	1.7	2.2	2.1	3.2	3.1
	Massachusetts	0.7	0.7	-20.8	-20.0	-22.9	-20.0	-23.4	-20.0	-15.7	-20.0	-14.8	-20.0	-14.1	-20.0
	Maryland	0.6	0.6	-25.2	-20.0	-27.9	-20.0	-28.5	-20.0	-19.0	-20.0	-18.0	-20.0	-17.0	-20.0
	Maine	1.0	1.0	-23.7	-20.0	-25.7	-20.0	-26.1	-20.0	-19.6	-20.0	-19.1	-20.0	-18.8	-20.0
	Michigan	0.7	0.7	0.9	0.9	1.7	1.6	1.9	1.9	-26.1	-20.0	-25.1	-20.0	-24.2	-20.0
	Minnesota	0.7	0.7	0.8	0.7	1.5	1.4	1.7	1.7	-22.3	-20.0	-21.4	-20.0	-20.5	-20.0
	Missouri	0.6	0.6	0.9	0.9	1.7	1.6	1.9	1.8	5.3	5.0	6.8	6.4	9.4	9.1
	Mississippi	1.1	1.1	1.3	1.3	2.5	2.5	2.9	2.9	5.9	6.0	7.7	7.7	10.3	10.6
	Montana	0.7	0.7	0.9	0.9	1.6	1.6	2.0	1.9	5.5	5.1	7.0	6.5	9.6	9.3
	North Carolina	0.7	0.7	1.1	1.1	1.9	1.8	2.2	2.1	-24.3	-20.0	-22.9	-20.0	-21.6	-20.0
	North Dakota	0.7	0.7	1.1	1.0	1.8	1.7	2.1	2.0	6.1	5.6	7.7	7.2	10.4	10.0
	Nebraska	0.4	0.4	0.6	0.6	1.1	1.0	1.3	1.2	3.9	3.6	5.0	4.7	7.1	6.9
	New Hampshire	1.1	1.1	-22.2	-20.0	-24.1	-20.0	-24.4	-20.0	-17.7	-20.0	-17.0	-20.0	-16.5	-20.0
	New Jersey	0.5	0.5	0.7	0.7	1.3	1.2	1.5	1.4	-13.4	-20.0	-12.9	-20.0	-12.5	-20.0
	New Mexico	0.8	0.8	1.1	1.1	2.0	1.9	2.4	2.3	-51.2	-20.0	-48.1	-20.0	-43.3	-20.0
	Nevada	0.3	0.3	0.7	0.7	1.1	1.0	1.5	1.4	3.7	3.4	-19.6	-20.0	-18.3	-20.0
	New York	0.5	0.5	-16.7	-20.0	-18.2	-20.0	-18.5	-20.0	-13.3	-20.0	-12.8	-20.0	-12.3	-20.0
	Ohio	0.6	0.6	0.9	0.9	1.6	1.6	1.9	1.8	4.6	4.5	5.9	5.8	8.1	8.1
	Oklahoma	0.5	0.5	0.8	0.8	1.4	1.3	1.6	1.6	4.3	3.9	5.6	5.2	7.9	7.5
	Oregon	1.0	1.0	0.6	0.6	1.6	1.7	-20.4	-20.0	-14.9	-20.0	-14.3	-20.0	-13.7	-20.0
	Pennsylvania	0.5	0.5	1.0	1.0	1.6	1.5	1.8	1.7	4.3	4.2	5.4	5.4	7.5	7.5
	Rhode Island	0.5	0.5	-24.6	-20.0	-27.5	-20.0	-28.1	-20.0	-18.6	-20.0	-17.7	-20.0	-16.9	-20.0
	South Carolina	1.0	1.0	1.3	1.3	2.5	2.4	2.8	2.8	5.6	5.9	-24.1	-20.0	-23.0	-20.0
	South Dakota	0.6	0.6	0.7	0.7	1.3	1.3	1.6	1.6	3.3	3.4	4.2	4.2	5.4	5.5
	Tennessee	0.6	0.6	0.8	0.7	1.4	1.3	1.6	1.5	3.9	3.8	5.1	4.9	-25.7	-20.0
	Texas	0.6	0.6	0.6	0.6	1.2	1.2	1.4	1.4	3.3	3.3	4.3	4.2	-21.9	-20.0
	Utah	0.9	0.9	0.9	0.9	1.8	1.8	2.2	2.2	5.6	5.3	7.1	6.8	9.9	9.7
	Virginia	0.7	0.7	1.1	1.1	1.8	1.8	2.1	2.0	-20.7	-20.0	-19.4	-20.0	-18.2	-20.0
	Vermont	0.9	0.9	-21.4	-20.0	-23.3	-20.0	-23.7	-20.0	-17.7	-20.0	-17.4	-20.0	-17.4	-20.0
	Washington	0.8	0.8	0.5	0.5	1.3	1.3	-17.0	-20.0	-12.3	-20.0	-11.9	-20.0	-11.4	-20.0
	Wisconsin	0.6	0.6	0.8	0.8	1.5	1.5	1.7	1.7	-28.5	-20.0	-27.4	-20.0	-26.3	-20.0
	West Virginia	0.6	0.6	1.8	1.7	2.6	2.3	2.9	2.6	8.1	7.4	10.2	9.5	13.4	12.9
	Wyoming	0.6	0.6	1.1	1.1	1.9	1.7	2.2	2.1	7.3	6.4	9.3	8.4	13.0	12.2
National Emissions (% Change)		-0.8	-0.8	-0.7	-0.7	-1.4	-1.5	-1.7	-1.7	-4.2	-4.4	-5.4	-5.5	-9.2	-9.2
Leakage (%)		44.3	44.3	53.5	52.8	48.2	46.8	47.3	45.9	40.4	38.8	37.1	35.8	26.0	25.6

Source: Authors calculations.

production structure. The main results here assume the KLEM functional form. Results based on the core production structure are reported in the appendix.

Table 10 characterizes impacts to emissions levels and leakage rates for a model with gravity based bilateral trade. Scenarios differ by permit trade across included policy states (*No Trade* or *Trade*). Emissions impacts are presented in percentage change from reference emissions levels. In both the California and RGGI scenarios, a 20% reduction in emissions leads to a roughly 1% reduction in country wide emissions. As more states are included in emissions reductions policies, the total level of US emissions decreases by roughly 9% in the *Climate Mayors* simulation.

Emissions decreases in states included in the policy shock are complemented by increases elsewhere in the economy to compensate for lost production. Particularly large percentage increases occur in states that serve as trading partners with states with implemented carbon standards (especially for electricity). For instance, in the California only case, Arizona has a large percent increase in emissions relative to other unaffected states. Emissions increases in states due to reductions elsewhere in the country tend to decrease when more states are included in the climate policies and depend on regional trading patterns. The highest leakage rate of 54% occurs under the RGGI policy. The leakage rates calculated here are similar to those reported by Caron et al. (2015). Imposing constrained trade relations in the model with our gravity estimates leads to larger leakage rates when permits are tradable.

We contrast the gravity based results with those from a model with a pooled national market, as shown in Table 11. A pooled national market simplifies trade by assuming a single national price for each nationally traded good. As the model does not specify trading partners, emissions increases in states outside of the policy does not reflect proximity. For instance, in the California only policy, states with the largest emissions increases are those on the east coast. Country wide emissions changes are smaller relative to the gravity based case, because leakage rates are higher in the pooled market. Leakage rates range from 61% in the RGGI case to 29% in the Climate Mayors scenario. Leakage rates are higher in this case because trade is not constrained to region pairings. Tradable permits (across regions) in a pooled national market result in smaller leakage rates compared to fixed regional permits, differing from the case of bilateral trade flows. These trends are reported in Figure 12.

Tables 12 and 13 report the per capita equivalent variation (measured in $ per capita) across policy designs for both gravity trade and a pooled national market with the KLEM production function. Permit revenues are assumed to accrue to the representative government agent. As a result of an equal yield constraint, any additional revenue received by the government is transferred back to the household agent via a lump sum payment. On average, the model calculates negative welfare impacts due to carbon standards across the United States. As a pooled national market results in greater levels of leakage in the economy, welfare losses are smaller than in the gravity trade case. The average impact across the country ranges from [-$215, -$21] per capita in a pooled market to [-$230, -$27] with bilateral trade flows. Significant variation, however, exists at the state level. For instance, impacts to D.C. tend to be large due to a combination of relatively large equivalent variation as a percentage of reference income weighted by a smaller population size. In the California only scenario, D.C. has a computed equivalent variation as a percentage of reference income of -0.3% relative to -0.4% in California. Moreover, the assumption made on trade can flip the sign of the impact. For instance, in the California only policy proposal, explicit bilateral trade links California with

Table 11. Carbon emissions and leakage rates: pooled national market and KLEM production structure (%)

		CA		RGGI		CA-RGGI		History		State Alliance		Carbon Center		Climate Mayors	
		Trade	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*
State Emissions % Change	*Alaska*	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.4	1.3	1.2	1.6	1.6	-21.4	-20.0
	Alabama	1.4	1.4	1.5	1.6	3.1	3.1	3.6	3.6	7.8	8.0	10.0	10.2	14.0	14.3
	Arkansas	1.1	1.1	1.2	1.3	2.5	2.5	2.9	2.9	6.6	6.7	-30.3	-20.0	-28.3	-20.0
	Arizona	0.8	0.8	0.9	1.0	1.9	1.9	2.2	2.2	5.3	5.3	6.9	6.9	-23.1	-20.0
	California	-20.0	-20.0	0.8	0.8	-16.7	-20.0	-17.1	-20.0	-12.5	-20.0	-11.5	-20.0	-11.0	-20.0
	Colorado	0.7	0.7	0.8	0.9	1.6	1.6	1.9	1.9	-30.8	-20.0	-28.5	-20.0	-27.0	-20.0
	Connecticut	0.8	0.8	-14.4	-20.0	-16.8	-20.0	-17.2	-20.0	-12.6	-20.0	-11.6	-20.0	-11.1	-20.0
	D.C.	0.6	0.6	0.7	0.7	1.3	1.4	1.5	1.6	2.7	2.9	-9.2	-20.0	-9.2	-20.0
	Delaware	1.3	1.3	-31.5	-20.0	-38.5	-20.0	-40.1	-20.0	-26.8	-20.0	-24.7	-20.0	-23.7	-20.0
	Florida	1.0	1.0	1.1	1.2	2.3	2.3	2.6	2.7	5.8	5.9	-22.4	-20.0	-20.8	-20.0
	Georgia	0.8	0.8	0.9	1.0	1.8	1.9	2.1	2.2	5.0	5.0	6.5	6.6	9.2	9.3
	Hawaii	0.8	0.8	1.0	1.0	1.9	2.0	2.2	2.3	-31.4	-20.0	-26.3	-20.0	-23.5	-20.0
	Iowa	0.8	0.8	0.9	0.9	1.7	1.8	2.0	2.1	4.7	4.7	6.0	6.1	8.6	8.8
	Idaho	0.9	0.9	0.8	0.8	1.8	1.8	2.1	2.1	3.4	3.8	4.3	4.7	5.9	6.4
	Illinois	0.7	0.7	0.8	0.8	1.6	1.6	1.9	1.9	-20.8	-20.0	-19.7	-20.0	-19.0	-20.0
	Indiana	0.7	0.7	0.9	1.0	1.8	1.8	2.1	2.1	5.6	5.5	7.2	7.2	10.4	10.4
	Kansas	0.7	0.7	0.8	0.9	1.7	1.7	2.0	2.0	4.9	4.9	6.3	6.3	9.1	9.2
	Kentucky	1.0	1.0	1.2	1.3	2.3	2.3	2.7	2.7	6.9	6.8	8.8	8.8	12.6	12.7
	Louisiana	0.3	0.3	0.3	0.3	0.7	0.7	0.8	0.8	1.9	1.9	2.4	2.5	3.6	3.7
	Massachusetts	1.2	1.2	-19.5	-20.0	-23.1	-20.0	-23.8	-20.0	-16.1	-20.0	-14.5	-20.0	-13.6	-20.0
	Maryland	0.9	0.9	-21.5	-20.0	-25.5	-20.0	-26.3	-20.0	-18.3	-20.0	-16.8	-20.0	-15.8	-20.0
	Maine	2.1	2.1	-48.0	-20.0	-52.3	-20.0	-52.9	-20.0	-44.2	-20.0	-41.0	-20.0	-40.2	-20.0
	Michigan	1.0	1.0	1.1	1.1	2.2	2.3	2.6	2.6	-27.3	-20.0	-25.5	-20.0	-24.5	-20.0
	Minnesota	0.8	0.8	0.8	0.9	1.7	1.8	2.0	2.0	-21.4	-20.0	-20.1	-20.0	-19.3	-20.0
	Missouri	0.7	0.7	0.9	1.0	1.7	1.7	2.0	2.0	5.4	5.3	7.0	6.9	10.1	10.0
	Mississippi	2.1	2.1	1.9	2.0	4.1	4.2	4.8	4.9	8.7	9.3	11.1	11.7	15.1	15.8
	Montana	0.7	0.7	0.8	0.9	1.6	1.6	1.9	1.9	5.4	5.2	7.0	6.9	10.2	10.1
	North Carolina	1.0	1.0	1.1	1.1	2.1	2.2	2.5	2.5	-24.2	-20.0	-22.4	-20.0	-21.1	-20.0
	North Dakota	0.8	0.8	0.9	1.0	1.8	1.9	2.1	2.1	4.6	4.6	6.1	6.0	9.3	9.1
	Nebraska	0.4	0.4	0.6	0.6	1.1	1.1	1.3	1.3	3.8	3.7	4.9	4.8	7.3	7.3
	New Hampshire	2.0	2.0	-42.3	-20.0	-47.1	-20.0	-47.8	-20.0	-36.5	-20.0	-32.7	-20.0	-31.3	-20.0
	New Jersey	0.6	0.6	0.6	0.7	1.4	1.4	1.6	1.6	-12.3	-20.0	-11.6	-20.0	-11.2	-20.0
	New Mexico	0.9	0.9	1.1	1.2	2.2	2.2	2.6	2.6	-55.1	-20.0	-54.6	-20.0	-54.6	-20.0
	Nevada	0.7	0.7	0.8	0.9	1.7	1.7	1.9	2.0	4.5	4.5	-17.8	-20.0	-16.8	-20.0
	New York	0.7	0.7	-14.0	-20.0	-16.2	-20.0	-16.6	-20.0	-12.2	-20.0	-11.3	-20.0	-10.8	-20.0
	Ohio	0.8	0.8	0.9	0.9	1.8	1.8	2.1	2.1	5.0	5.0	6.4	6.5	9.2	9.4
	Oklahoma	0.6	0.6	0.7	0.8	1.4	1.5	1.7	1.7	4.5	4.4	5.8	5.8	8.4	8.4
	Oregon	0.9	0.9	0.9	0.9	1.9	1.9	-19.6	-20.0	-14.5	-20.0	-13.4	-20.0	-12.8	-20.0
	Pennsylvania	0.6	0.6	0.8	0.8	1.5	1.5	1.8	1.8	4.5	4.5	5.8	5.8	8.4	8.4
	Rhode Island	1.0	1.0	-23.3	-20.0	-28.2	-20.0	-29.2	-20.0	-19.6	-20.0	-17.9	-20.0	-16.8	-20.0
	South Carolina	2.1	2.1	2.0	2.0	4.2	4.2	4.8	4.9	8.5	9.2	-40.6	-20.0	-39.1	-20.0
	South Dakota	1.1	1.1	1.0	1.1	2.2	2.2	2.5	2.6	4.5	4.9	5.7	6.1	7.8	8.3
	Tennessee	0.6	0.6	0.7	0.8	1.4	1.5	1.7	1.7	4.1	4.1	5.3	5.4	-25.7	-20.0
	Texas	0.7	0.7	0.7	0.7	1.5	1.5	1.7	1.7	3.9	3.9	5.0	5.1	-21.6	-20.0
	Utah	0.8	0.8	0.9	1.0	1.8	1.9	2.2	2.2	5.7	5.6	7.4	7.3	10.6	10.7
	Virginia	0.9	0.9	1.0	1.0	2.0	2.0	2.3	2.3	-19.8	-20.0	-18.2	-20.0	-17.1	-20.0
	Vermont	1.9	1.9	-44.7	-20.0	-50.5	-20.0	-51.3	-20.0	-38.5	-20.0	-34.3	-20.0	-33.2	-20.0
	Washington	0.7	0.7	0.6	0.6	1.3	1.4	-15.1	-20.0	-11.3	-20.0	-10.6	-20.0	-10.3	-20.0
	Wisconsin	0.8	0.8	0.9	0.9	1.7	1.8	2.0	2.1	-28.1	-20.0	-26.5	-20.0	-25.5	-20.0
	West Virginia	0.9	0.9	1.3	1.4	2.4	2.4	2.8	2.8	8.3	7.8	10.7	10.3	15.2	14.9
	Wyoming	0.7	0.7	1.0	1.2	1.9	1.9	2.2	2.2	7.3	6.8	9.4	9.0	13.7	13.4
National Emissions (% Change)		-0.6	-0.6	-0.6	-0.6	-1.2	-1.2	-1.5	-1.4	-3.9	-3.9	-5.1	-5.1	-8.8	-8.8
Leakage (%)		55.9	55.9	57.2	61.1	55.2	56.3	54.6	55.4	44.8	45.0	40.6	40.8	29.3	29.5

Source: Authors calculations.

nearby regions (e.g. Utah, Nevada) producing relatively large (in absolute value) per capita impacts. This effect disappears in the pooled market simulation.

Results based on the canonical production are provided in the appendix. This structure does not allow energy substitution, therefore any output impacts due to emissions policies cannot be mitigated through substituting to less carbon intensive energy. This leads to higher prices for linked sectors. Higher state wide prices result in much higher leakage rates (for core production based results, see Appendix D). Gravity based leakage rates (ranging up to 128%) tend to be higher than pooled rates (ranging up to 121%). Notably, when the leakage rate is greater

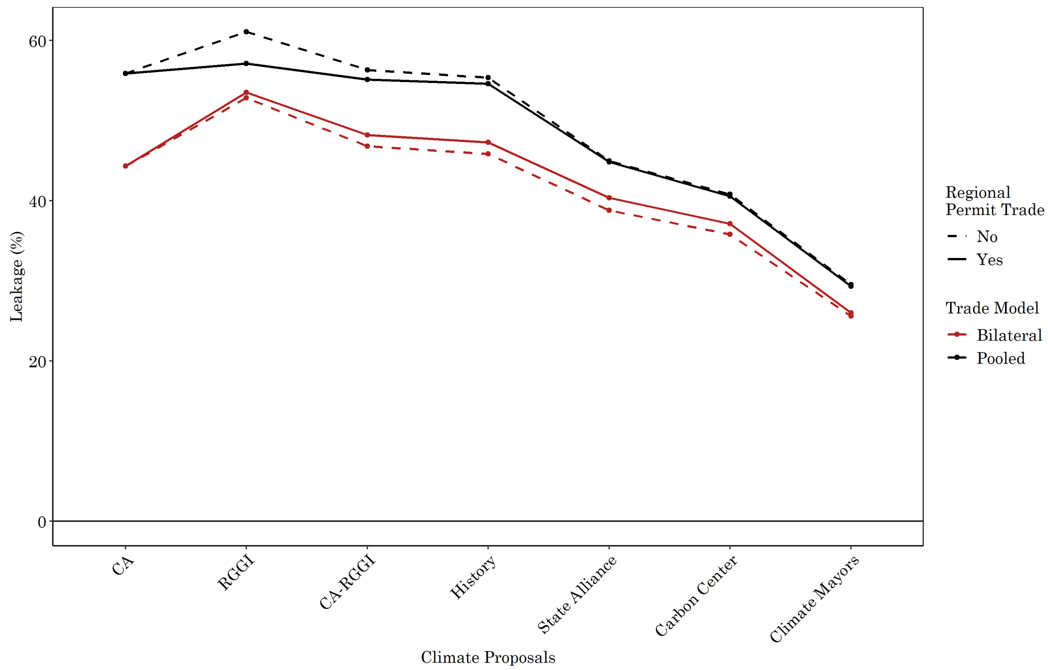

Figure 12. Leakage rate comparison across model permutations

Source: Authors calculations.

than 100%, post policy country-wide emissions increase. These trends are contrary to KLEM results discussed above. The lack of substitutability in the production structure leads to a model that forces larger output based effects. In general, emissions increases in states outside of the policy space increase considerably more than those calculated with a KLEM production function due to the inflexible treatment of carbon intensive energy use. Welfare impacts also follow the same trend as those reported above, though they are scaled.

5.2.4 Sensitivity: Stringency of Reductions

We also report result sensitivity to the size of the policy shock. Figure 13 describes leakage rates (left, in percent) and corresponding national emissions changes (right, in percent change) due to varying levels of emissions reduction stringencies. Here, we consider the non-tradable permit case with a KLEM production function. Note that we make no attempt to study differentiated emissions policies. States included in each policy scenario are mandated to reduce emissions by a fixed percentage. Figure 13 considers the impacts from a 10-50% reduction in state level carbon emissions. The number of included states increases from top to bottom. In all cases, the level of leakage is higher whe we assume a pooled national market, leading to smaller changes in absolute value in national emissions levels. Across trade based assumptions, the leakage curve is steepest when a small number of

Table 12. Per Capita equivalent variation: gravity trade and KLEM production structure ($ per capita)

	CA		**RGGI**		**CA-RGGI**		**History**		**State Alliance**		**Carbon Center**		**Climate Mayors**	
	Trade	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*
Alaska	122.0	122.0	77.7	82.3	203.2	215.4	222.8	233.0	250.4	343.2	329.1	426.7	-56.3	68.0
Alabama	0.2	0.2	14.6	14.1	18.1	15.5	22.0	18.9	57.9	52.4	45.4	44.5	36.7	40.8
Arkansas	3.6	3.6	21.5	21.3	29.0	26.8	36.4	34.0	74.1	74.7	145.8	58.4	-10.8	-61.0
Arizona	-89.1	-89.1	3.6	3.6	-76.1	-87.4	-81.2	-92.4	-62.0	-98.1	-57.1	-95.4	-144.5	-198.4
California	-158.0	-158.0	-21.8	-20.5	-184.9	-186.6	-210.1	-212.5	-232.2	-266.9	-271.4	-310.5	-335.4	-379.3
Colorado	-45.6	-45.6	-5.5	-5.3	-47.2	-51.6	-57.8	-63.2	-90.4	-153.0	-116.2	-170.9	-205.8	-249.7
Connecticut	-35.7	-35.7	-154.1	-162.8	-203.8	-209.2	-216.3	-221.0	-229.8	-282.4	-256.3	-314.1	-318.5	-384.1
D.C.	-213.5	-213.5	-239.5	-238.4	-469.7	-468.6	-527.5	-525.4	-803.6	-929.5	-1057.2	-1200.8	-1530.4	-1691.1
Delaware	-80.0	-80.0	15.1	-70.5	-32.0	-160.1	-40.3	-177.8	-188.4	-267.9	-255.9	-329.0	-393.3	-465.8
Florida	1.6	1.6	-15.9	-13.1	-16.3	-11.3	-17.2	-11.9	-40.4	-33.2	-112.4	-113.4	-151.7	-147.7
Georgia	-2.0	-2.0	-3.7	-2.8	-5.1	-4.0	-5.1	-3.9	-42.2	-32.9	-113.2	-93.6	-159.5	-138.4
Hawaii	-67.6	-67.6	-12.6	-9.6	-74.0	-77.2	-102.1	-107.2	-262.2	-289.9	-299.7	-322.0	-438.1	-450.1
Iowa	-13.5	-13.5	8.4	7.5	-2.0	-5.5	-1.5	-5.6	-57.7	-53.2	-54.8	-52.6	-72.9	-71.8
Idaho	-88.6	-88.6	5.6	5.7	-73.6	-85.0	-99.2	-116.2	-80.3	-125.4	-85.1	-132.6	-119.9	-170.8
Illinois	2.2	2.2	-8.1	-7.3	-6.4	-4.6	-6.2	-4.2	-133.1	-124.6	-147.5	-136.8	-166.7	-155.0
Indiana	3.1	3.1	-3.9	-4.8	-1.5	-1.6	-0.2	-0.1	-101.0	-82.5	-110.5	-94.3	-105.2	-95.4
Kansas	-18.2	-18.2	9.5	9.4	-4.6	-8.1	-3.2	-7.1	-20.2	-17.0	-16.9	-14.3	-92.4	-83.0
Kentucky	6.9	6.9	8.4	8.0	16.9	16.3	21.2	20.6	-26.7	-11.9	-30.7	-15.7	-61.7	-41.5
Louisiana	-2.8	-2.8	-16.9	-17.3	-21.1	-19.9	-20.8	-19.1	-50.0	-47.2	-86.3	-79.9	-252.4	-233.5
Massachusetts	-37.4	-37.4	-125.3	-139.8	-168.6	-187.0	-181.7	-201.4	-264.6	-306.9	-307.2	-352.7	-384.3	-437.2
Maryland	-29.4	-29.4	-8.5	-41.1	-21.3	-74.3	-25.0	-82.9	-186.7	-201.8	-231.3	-245.3	-311.4	-326.5
Maine	-27.4	-27.4	46.0	1.1	43.4	-33.0	44.8	-38.8	-38.2	-59.3	-58.7	-76.2	-101.8	-118.9
Michigan	-10.0	-10.0	-20.8	-21.5	-33.4	-32.9	-37.8	-37.1	-109.1	-143.1	-135.9	-166.0	-160.6	-192.2
Minnesota	-10.7	-10.7	-7.2	-7.6	-17.7	-18.7	-21.3	-22.6	-138.7	-141.8	-159.5	-160.0	-194.9	-194.8
Missouri	-4.9	-4.9	3.4	3.3	0.1	-0.9	0.7	-0.5	-40.9	-33.0	-53.7	-42.9	-91.6	-78.6
Mississippi	-10.6	-10.6	5.2	4.8	-2.7	-5.1	-0.8	-3.3	6.8	3.5	-4.5	-5.2	-73.9	-67.2
Montana	-53.7	-53.7	31.6	32.1	-10.9	-21.3	-17.2	-31.3	40.1	7.9	72.5	37.5	94.1	59.4
North Carolina	-18.8	-18.8	-26.9	-26.4	-47.7	-46.6	-53.6	-52.4	-121.4	-150.0	-209.6	-224.3	-280.2	-293.5
North Dakota	-35.4	-35.4	64.1	64.5	44.3	32.6	47.8	32.5	108.2	87.2	181.3	155.7	203.0	185.7
Nebraska	62.8	62.8	63.5	65.3	132.7	135.0	158.9	161.4	194.1	249.7	253.9	311.6	318.3	387.3
New Hampshire	-46.6	-46.6	-8.6	-34.6	-42.6	-89.9	-49.1	-101.0	-109.5	-139.5	-138.3	-166.4	-207.3	-235.8
New Jersey	-4.5	-4.5	-80.7	-98.5	-96.9	-106.2	-100.8	-108.3	-167.6	-186.4	-180.6	-202.2	-199.3	-225.7
New Mexico	-96.9	-96.9	4.5	4.5	-82.5	-94.2	-90.8	-103.3	159.0	-159.5	123.5	-167.2	-120.7	-356.5
Nevada	-255.6	-255.6	-4.7	-5.2	-236.2	-266.8	-245.6	-273.8	-198.9	-304.7	-307.4	-418.5	-385.2	-502.6
New York	-32.7	-32.7	-141.3	-136.1	-186.4	-176.5	-199.6	-188.8	-268.7	-322.2	-297.3	-358.0	-353.5	-423.2
Ohio	-2.7	-2.7	-20.8	-20.8	-26.2	-24.0	-28.1	-25.4	-115.3	-101.5	-134.1	-121.9	-149.4	-142.1
Oklahoma	21.0	21.0	25.2	25.1	49.4	49.2	60.5	60.2	82.1	97.5	113.6	127.9	-26.2	8.9
Oregon	-53.2	-53.2	7.1	6.6	-39.2	-47.5	-129.4	-148.9	-107.5	-149.9	-103.6	-148.6	-98.9	-148.9
Pennsylvania	1.0	1.0	-66.5	-67.9	-75.3	-68.9	-77.6	-69.5	-91.5	-118.2	-90.2	-121.5	-78.0	-115.1
Rhode Island	-53.5	-53.5	-49.1	-77.0	-91.4	-138.7	-98.7	-150.3	-159.9	-197.5	-202.7	-238.0	-298.3	-334.6
South Carolina	-10.0	-10.0	-1.1	-2.1	-10.1	-12.2	-11.0	-13.3	-57.5	-54.6	-31.3	-69.1	-65.8	-97.9
South Dakota	-86.8	-86.8	1.7	1.2	-76.1	-87.6	-86.7	-99.8	-92.6	-129.0	-108.3	-145.9	-225.0	-259.3
Tennessee	8.0	8.0	4.5	4.6	13.0	13.8	16.2	17.2	-28.8	-10.8	-47.0	-25.7	-53.3	-72.4
Texas	2.8	2.8	-23.4	-21.0	-23.6	-18.0	-27.1	-21.1	-73.2	-55.7	-107.4	-83.5	-316.6	-305.4
Utah	-90.7	-90.7	6.0	5.8	-75.0	-86.6	-85.2	-98.1	-75.0	-109.5	-71.4	-108.9	-105.5	-143.4
Virginia	-22.7	-22.7	-70.5	-62.3	-101.2	-87.5	-109.5	-94.6	-206.8	-214.8	-264.4	-267.7	-357.0	-359.0
Vermont	-48.7	-48.7	27.5	13.5	-2.1	-42.9	-2.7	-48.8	-27.4	-45.6	-43.4	-59.7	-94.5	-111.2
Washington	-47.2	-47.2	-12.4	-11.0	-56.8	-59.5	-236.8	-233.8	-233.5	-271.8	-246.8	-289.2	-289.4	-336.1
Wisconsin	-5.0	-5.0	-0.9	-1.7	-5.4	-6.7	-5.9	-7.3	-86.1	-125.5	-106.9	-141.7	-134.9	-168.9
West Virginia	3.2	3.2	28.7	26.8	38.0	31.5	44.3	36.8	61.6	55.1	81.1	74.3	96.4	92.4
Wyoming	-1.4	-1.4	80.1	90.3	96.3	93.7	99.4	93.9	-184.8	-119.3	-132.8	-83.5	-180.8	-141.0
USA	-34.6	-34.6	-26.9	-28.1	-62.8	-64.9	-74.0	-76.2	-118.3	-135.0	-146.3	-164.3	-210.7	-231.0

Source: Authors calculations.

states are included. As the policy level of emissions reductions increases, goods become relatively more expensive, incentivizing substitution of locally produced carbon intensive goods. Moreover, as more states are included in the set of regions requiring emissions reductions, the curve shifts downward and flattens. The emissions reduction curve correspondingly steepens.

Table 13. Per capita equivalent variation: pooled national market and KLEM production structure ($ per capita)

	CA		RGGI		CA-RGGI		History		State Alliance		Carbon Center		Climate Mayors	
	Trade	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*
Alaska	145.1	145.1	105.8	104.0	258.6	267.0	302.9	311.2	391.5	489.1	512.0	610.9	-261.9	-96.8
Alabama	23.2	23.2	20.3	23.4	46.6	49.9	55.2	58.5	120.9	129.3	156.9	168.5	242.9	257.0
Arkansas	39.6	39.6	29.6	29.8	71.7	74.2	84.7	87.3	131.9	154.6	-150.4	-64.9	-116.8	-35.0
Arizona	1.0	1.0	5.2	6.9	8.3	9.1	9.5	10.2	21.8	24.3	30.2	33.9	-163.2	-145.3
California	-273.8	-273.8	-7.4	-7.2	-260.1	-298.3	-274.0	-306.8	-254.4	-354.9	-269.7	-384.0	-309.8	-435.6
Colorado	-3.9	-3.9	0.8	2.0	-1.3	-0.8	-1.9	-1.6	-174.5	-146.1	-188.1	-160.8	-222.8	-195.5
Connecticut	-22.7	-22.7	-170.6	-217.5	-227.3	-255.9	-242.0	-266.7	-232.8	-319.2	-250.5	-349.0	-296.7	-407.0
D.C.	-174.6	-174.6	-119.0	-114.3	-298.2	-305.4	-354.2	-362.4	-568.4	-643.9	-868.6	-1060.8	-1279.3	-1487.1
Delaware	-30.1	-30.1	-297.1	-220.9	-387.6	-272.0	-411.3	-287.0	-407.5	-379.7	-439.3	-429.8	-520.7	-523.7
Florida	7.7	7.7	8.5	9.4	17.9	19.0	20.8	21.9	23.2	33.8	-167.3	-146.5	-191.3	-175.8
Georgia	4.5	4.5	6.7	8.4	13.4	14.9	15.5	17.0	12.8	24.7	15.2	28.9	14.1	31.4
Hawaii	-12.2	-12.2	3.2	9.8	-3.1	0.4	-4.9	-2.0	-211.5	-175.0	-223.7	-192.9	-291.7	-261.9
Iowa	20.2	20.2	15.2	15.0	36.8	37.9	43.9	45.2	68.1	81.2	88.0	101.9	139.9	156.3
Idaho	11.6	11.6	5.6	5.4	16.9	18.2	20.1	21.6	8.2	21.2	8.0	21.4	15.9	30.4
Illinois	13.7	13.7	11.8	12.7	27.7	29.0	32.9	34.3	-241.1	-222.9	-235.8	-230.2	-238.4	-240.9
Indiana	17.8	17.8	4.6	3.6	21.2	23.0	26.4	28.6	29.5	42.4	34.3	47.9	77.9	91.5
Kansas	16.5	16.5	9.8	11.2	27.5	30.4	32.9	35.8	49.0	63.8	61.0	77.9	95.9	116.0
Kentucky	34.5	34.5	22.1	22.5	58.0	61.2	68.5	71.9	83.2	109.7	105.1	133.0	155.3	187.6
Louisiana	12.4	12.4	-17.3	-20.8	-10.2	-7.7	-8.5	-5.0	-31.9	-21.6	-44.6	-34.3	0.9	8.4
Massachusetts	-23.8	-23.8	-206.8	-212.0	-273.4	-255.3	-290.5	-267.6	-290.6	-341.5	-314.6	-382.6	-379.2	-462.5
Maryland	-21.7	-21.7	-154.3	-145.4	-201.3	-178.8	-214.0	-188.8	-236.9	-250.5	-268.9	-290.0	-342.1	-372.0
Maine	11.1	11.1	-339.4	-181.9	-352.0	-197.0	-353.5	-201.4	-359.9	-221.1	-357.2	-232.4	-366.9	-247.7
Michigan	0.9	0.9	-0.8	-1.0	-0.3	-0.1	0.2	0.6	-291.6	-236.8	-302.3	-260.3	-320.9	-288.8
Minnesota	10.0	10.0	6.1	5.8	16.7	17.3	20.2	20.9	-246.1	-227.8	-249.5	-243.7	-260.9	-264.5
Missouri	8.9	8.9	6.6	7.3	16.5	17.9	19.8	21.3	24.4	34.6	30.1	41.6	50.1	63.4
Mississippi	29.1	29.1	18.8	19.4	49.0	51.9	58.1	61.1	90.4	108.1	115.9	135.1	176.9	199.3
Montana	42.4	42.4	27.3	28.3	71.8	75.5	84.8	88.6	130.9	150.3	173.9	194.6	266.9	290.6
North Carolina	-17.4	-17.4	-12.7	-10.6	-30.2	-29.1	-35.5	-34.4	-253.8	-238.4	-287.9	-278.6	-355.3	-353.8
North Dakota	70.2	70.2	63.9	68.0	143.2	149.1	165.9	170.7	247.8	284.3	346.7	383.6	539.7	582.9
Nebraska	100.0	100.0	80.0	79.9	187.7	192.8	221.0	226.3	319.6	384.6	412.2	479.5	582.2	664.8
New Hampshire	-11.9	-11.9	-281.3	-168.0	-322.2	-204.1	-331.3	-214.1	-319.4	-249.4	-323.7	-271.3	-352.1	-310.7
New Jersey	5.9	5.9	4.5	4.1	11.1	11.1	13.3	13.4	-207.6	-297.7	-209.4	-312.7	-222.4	-335.4
New Mexico	-2.0	-2.0	2.8	4.9	2.9	4.2	2.8	3.7	-132.2	-144.2	-164.1	-153.9	-208.8	-181.5
Nevada	-12.8	-12.8	-0.9	0.1	-10.5	-11.8	-13.0	-14.5	-24.1	-25.5	-272.2	-293.7	-330.7	-362.4
New York	-26.5	-26.5	-177.1	-240.4	-239.4	-283.0	-255.3	-294.6	-246.1	-354.5	-262.4	-386.0	-311.5	-448.5
Ohio	7.1	7.1	1.2	0.5	7.8	8.5	9.7	10.7	-1.1	8.2	-2.8	6.7	7.5	17.7
Oklahoma	41.1	41.1	26.4	24.8	69.1	71.2	81.8	83.9	117.6	141.7	159.1	183.6	247.6	276.8
Oregon	15.7	15.7	11.5	11.0	28.0	28.5	-192.6	-196.1	-150.0	-202.3	-139.6	-204.8	-121.3	-196.4
Pennsylvania	7.4	7.4	5.6	5.5	13.9	14.2	16.7	17.0	33.0	35.7	46.6	49.6	80.0	83.8
Rhode Island	-16.0	-16.0	-195.6	-175.8	-250.0	-206.3	-263.7	-215.2	-256.2	-269.5	-275.0	-301.2	-326.5	-364.1
South Carolina	12.6	12.6	10.1	11.0	23.4	25.0	27.7	29.3	42.7	52.1	-363.5	-229.4	-381.7	-255.3
South Dakota	6.3	6.3	5.7	6.3	13.0	13.9	15.3	16.3	17.8	25.7	22.3	31.2	33.0	43.7
Tennessee	20.3	20.3	12.9	11.9	33.9	34.9	40.2	41.4	35.4	54.9	43.7	63.2	-151.7	-111.2
Texas	9.1	9.1	-1.5	-2.3	7.0	8.5	9.3	11.1	5.3	14.8	8.9	19.2	-489.4	-461.4
Utah	9.8	9.8	8.1	9.0	19.5	20.8	23.2	24.5	36.4	44.6	48.0	57.4	76.8	88.2
Virginia	-18.1	-18.1	-9.5	-5.2	-26.2	-23.6	-31.6	-29.2	-258.0	-257.5	-292.9	-299.0	-377.4	-391.6
Vermont	6.8	6.8	-294.1	-163.3	-323.0	-179.0	-326.7	-182.8	-268.2	-180.7	-246.1	-178.5	-222.9	-163.5
Washington	-8.4	-8.4	-5.1	-2.4	-12.3	-10.5	-251.5	-304.7	-225.3	-337.3	-237.9	-359.3	-268.0	-397.8
Wisconsin	12.0	12.0	6.4	5.9	18.4	19.3	22.2	23.3	-201.3	-153.3	-210.1	-167.5	-219.7	-180.1
West Virginia	37.9	37.9	30.3	33.5	72.1	76.2	84.1	87.7	139.3	151.3	191.8	205.9	290.4	306.5
Wyoming	144.4	144.4	85.8	96.1	238.1	257.2	272.8	290.2	171.1	256.7	261.0	348.6	337.8	431.3
USA	-29.2	-29.2	-21.1	-23.4	-51.6	-55.5	-61.0	-65.0	-105.4	-120.6	-131.7	-149.5	-195.6	-215.8

Source: Authors calculations.

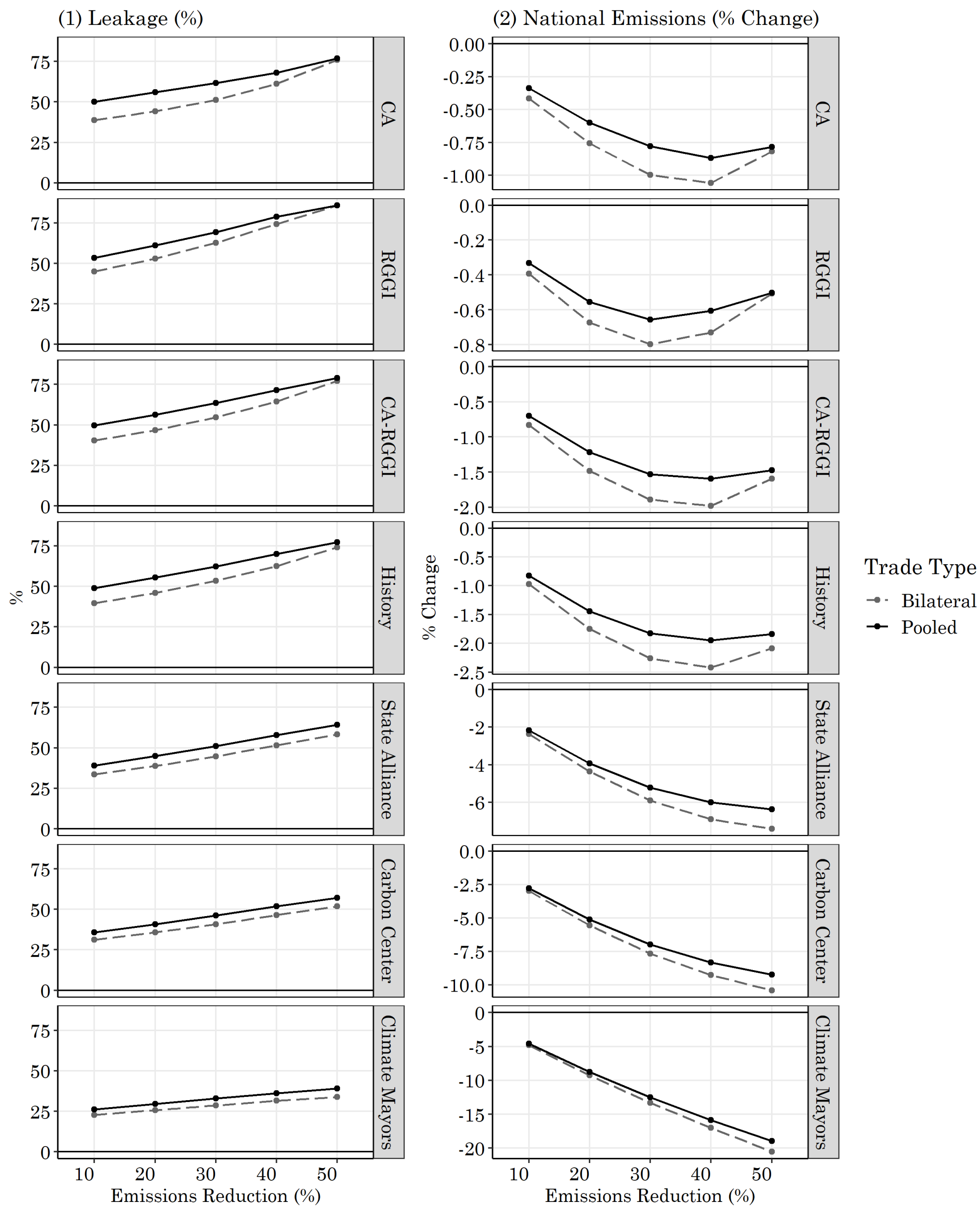

Figure 13. Sensitivity results with respect to mandated reductions in pollution

Source: Authors calculations.

6. Conclusions

In this paper we have introduced and discussed a transparent build stream that generates state level input output tables for the United States. We have shown that by using publicly available data it is possible to generate a dataset suitable for analyzing carbon leakage from state level climate action. These simulations illustrate that estimates for leakage depend on both modeling and data related assumptions, showing the importance of flexibility when preparing a dataset for policy analysis and the potential impacts on final results. National emissions changes due to subnational climate policies depend on the magnitude of leakage. Explicitly representing bilateral trade in the model constrains trading partners and is associated with smaller leakage rates (and larger national emissions changes) compared to a model with a pooled national market. Average welfare impacts are comparable across the two frameworks, though the distribution across states varies significantly.

Notably, our analysis is based on a relatively simple modeling framework and therefore readers should be cautious when interpreting results. More work is needed to achieve a comprehensive analysis of state level climate action. For instance, we refrain from discussing two step revenue recycling (through the tax system) which could have welfare implications for potential double dividends throughout the country. Further, we include only a single representative agent limiting the extent of capturing inter-household type distributional impacts. More work is also needed in the electricity sector. Assessing impacts of restricting emissions in electricity generation would require a more detailed representation of the types of technologies used to produce electricity across each state and trade, including ramping costs and constraints for satisfying peak and non-peak electricity demands. The results also rely on assumed trade elasticities in the Armington framework. Future research could evaluate the impact of various trade structures (e.g. Balistreri, Hillberry, and Rutherford (2011)) on subnational leakage rates. This point has been shown to be important in an international context (Balistreri and Rutherford, 2012).

We have largely focused on the logic of the build stream in this paper. Our intent is to provide the build stream, rather than simply a constructed dataset. The associated code is intended to serve as a basis for analysis for researchers interested in subnational modeling and modifiable if the need should arise. The assumptions made in this paper in the canonical framework may not be appropriate in the context of a given analysis (as illustrated by our modifications for assessing state level leakage). The flexibility detailed here allows users to generate alternative datasets to compare the outcomes of policy. Future extensions to the dataset could be based on spatial (e.g. sub-state delineations), distributional (e.g. household categories), or dataset linking (e.g. to GTAP) updates. Moreover, while the focus of this paper is on methods for producing regional social accounts in the United States, the same type of process could be leveraged in other countries (for instance, see Mi et al. (2018) for a somewhat similar exercise in China). While available regional data will vary depending on the country of interest, the same process of proportional scaling and reconciliation could be used to generate regionally consistent datasets from a national table elsewhere in the world.

This data construction effort for subnational policy analysis can benefit from economies of scale (Hertel, 1997). Similar in scope to the Global Trade and Analysis Project for international communities, developing a community user group to highlight new data sources or issues with the current version will increase the efficacy of the data build. The WiNDC build stream presented in this paper provides a mechanism for researchers to conduct analyses that may have otherwise been too costly. We have focused on describing the full build routine and modeling framework and pointed to aspects of the process that could be changed or improved in future research. These tools may contribute to new research, but also have the potential to improve the quality and reproducibility of applied general equilibrium modeling efforts in the United States.

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Appendix A. Sectoring Schemes

Table A.1. Core Sectoring Scheme

NAICS 2 Code	WiNDC Index	Description
Agriculture, Forestry, Fishing and Hunting (11)	*agr*	Farms (111CA)
	fof	Forestry, fishing, and related activities (113FF)
Mining, Quarrying and Oil and Gas Extraction (21)	*oil*	Oil and gas extraction (211)
	min	Mining, except oil and gas (212)
	smn	Support activities for mining (213)
Utilities (22)	*uti*	Utilities (22)
Construction (23)	*con*	Construction (23)
Manufacturing (31-33)	*fbp*	Food and beverage and tobacco products (311FT)
	tex	Textile mills and textile product mills (313TT)
	alt	Apparel and leather and allied products (315AL)
	wpd	Wood products (321)
	ppd	Paper products (322)
	pri	Printing and related support activities (323)
	pet	Petroleum and coal products (324)
	che	Chemical products (325)
	pla	Plastics and rubber products (326)
	nmp	Nonmetallic mineral products (327)
	pmt	Primary metals (331)
	fmt	Fabricated metal products (332)
	mch	Machinery (333)
	cep	Computer and electronic products (334)
	eec	Electrical equipment, appliances, and components (335)
	mot	Motor vehicles, bodies and trailers, and parts manufacturing (3361MV)
	ote	Other transportation equipment (3364OT)
	fpd	Furniture and related products (337)
	mmf	Miscellaneous manufacturing (339)
Wholesale Trade (42)	*wht*	Wholesale trade (42)
Retail Trade (44-45)	*mvt*	Motor vehicle and parts dealers (in the supply table) (441)
	fbt	Food and beverage stores (in the supply table) (445)
	gmt	General merchandise stores (in the supply table) (452)
	ott	Other retail (4A0)
Transportation and Warehousing (48-49)	*air*	Air transportation (481)
	trn	Rail transportation (482)
	wtt	Water transportation (483)
	trk	Truck transportation (484)
	grd	Transit and ground passenger transportation (485)
	pip	Pipeline transportation (486)
	otr	Other transportation and support activities (487OS)
	wrh	Warehousing and storage (493)
Information (51)	*pub*	Publishing industries, except internet (includes software) (511)
	mov	Motion picture and sound recording industries (512)
	brd	Broadcasting and telecommunications (513)
	dat	Data processing, internet publishing, and other information (514)
Finance and Insurance (52)	*bnk*	Federal Reserve banks, credit intermediation (521CI)
	sec	Securities, commodity contracts, and investments (523)
	ins	Insurance carriers and related activities (524)
	fin	Funds, trusts, and other financial vehicles (525)
Real Estate and Rental (53)	*hou*	Housing (5310HS)
	ore	Other real estate (531ORE)
	rnt	Rental and leasing services and lessors of intangible assets (532RL)
Professional Services (54)	*leg*	Legal services (5411)
	com	Computer systems design and related services (5415)
	tsv	Misc. professional, scientific, and technical services (5412OP)
Management (55)	*man*	Management of companies and enterprises (55)
Administrative (56)	*adm*	Administrative and support services (561)
	wst	Waste management and remediation services (562)
Education (61)	*edu*	Educational services (61)
Health Care and Assistance (62)	*amb*	Ambulatory health care services (621)
	hos	Hospitals (622)
	nrs	Nursing and residential care facilities (623)
	soc	Social assistance (624)
Arts and Recreation (71)	*art*	Performing arts, spectator sports, museums (711AS)
	rec	Amusements, gambling, and recreation industries (713)
Accomodation (72)	*amd*	Accommodation (721)
	res	Food services and drinking places (722)
Other Services (81)	*osv*	Other services, except government (81)
Public Administration (92)	*fdd*	Federal general government (defense) (S00500)
	fnd	Federal general government (nondefense) (S00600)
	fen	Federal government enterprises (GFE)
	slg	State and local general government (GSLG)
	sle	State and local government enterprises (GSLE)
	use	Scrap, used and secondhand goods (only in the use table) (Used)
	oth	Rest-of-the-world adjustment (only in the use table) (Other)

Appendix B. WiNDC Subroutines

1) `run.gms`: launching program for the WiNDC build stream. Options available for users to edit include an aggregation file, sector disaggregation and module generation.
2) `readbea.gms`: routine which collapses and converts downloaded BEA summary input output files (supply and use tables) into a singular file in a GAMS readable format, called GDX (GAMS Data Exchange).
3) `mapbea.gms`: mapping program that re-labels raw input output data sectoring schemes to non-numeric indices.
4) `partitionbea.gms`: matrix partitioning routine which allocates portions of the national input output table to associated CGE based parameters (e.g. intermediate input demand).
5) `calibrate.gms`: optimization based matrix balancing scripts enforces accounting identities in the national data.
6) `read2gdx.gms`: subroutine for translating raw datasets into GAMS readable formats.
7) `read*.gms`: data sources used for regionalization (see table 1) are read into GAMS and reconciled to match the core WiNDC sectoring scheme. The "*" indicates multiple programs with names that match the particular source of data that is being introduced into the routine.
8) `*share.gms`: regional shares based on "*" data are generated. Shares based on commodity flow survey data are calculated as *regional purchase coefficients*, or the share of nationally traded goods that remain within the region of production.
9) `statedisagg.gms`: state level regional disaggration routine. All shares are read into this program and used to disaggregate reconciled national data parameters. This routine outputs the *core* dataset.
10) `statemodel.gms`: state level accounting computable general equilibrium model used to verify benchmark consistency.
11) `sectordisagg.gms`: depending on the scope of the analysis, this routine disaggregates chosen aggregate sectors in the core 71 sectoring scheme from the detailed sector BEA files.
12) `aggregate.gms`: sectoral and/or regional aggregation routine.
13) `aggchk.gms`: consistency check on (dis)aggregation.
14) `bluenote.gms`: optional routine which recalibrates the WiNDC dataset to match additional satellite information (e.g. energy demands and supplies and emissions levels) for the energy-economy module.
15) `enforcechk.gms`: computable general equilibrium model used to verify benchmark consistency of the recalibrated dataset.
16) `mcp.gms`: provides a regional-level accounting computable general equilibrium model in both MPSGE and MCP used to verify benchmark consistency.

Appendix C. State Level Model GAMS Code: MPSGE and MCP

```
$title State Level MPSGE and MCP Model Code

$if not set year $set year 2016

set   yr    Year,
      r     States,
      s     Goods\sectors (national data),
      m     Margins (trade or transport),
      gm(s) Commodities employed in margin supply;

$gdxin 'WiNDCdatabase.gdx'
$loaddc yr r s m
alias(s,g),(r,rr);

parameter   ys0_(yr,r,g,s)    Sectoral supply,
            id0_(yr,r,s,g)    Intermediate demand,
            ld0_(yr,r,s)      Labor demand,
            kd0_(yr,r,s)      Capital demand,
            m0_(yr,r,s)       Imports,
            x0_(yr,r,s)       Exports of goods and services,
            rx0_(yr,r,s)      Re-exports of goods and services,
            md0_(yr,r,m,s)    Total margin demand,
            nm0_(yr,r,g,m)    Margin demand from national market,
            dm0_(yr,r,g,m)    Margin supply from local market,
            s0_(yr,r,s)       Aggregate supply,
            a0_(yr,r,s)       Armington supply,
            ta0_(yr,r,s)      Tax net subsidy rate on intermediate demand,
            tm0_(yr,r,s)      Import tariff,
            cd0_(yr,r,s)      Final demand,
            c0_(yr,r)         Aggregate final demand,
            yh0_(yr,r,s)      Household production,
            bopdef0_(yr,r)    Balance of payments,
            hhadj_(yr,r)      Household adjustment,
            g0_(yr,r,s)       Government demand,
            i0_(yr,r,s)       Investment demand,
            xn0_(yr,r,g)      Regional supply to national market,
            xd0_(yr,r,g)      Regional supply to local market,
            dd0_(yr,r,g)      Regional demand from local market,
            nd0_(yr,r,g)      Regional demand from national market;

* Production data:

$loaddc ys0_ ld0_ kd0_ id0_

* Consumption data:

$loaddc yh0_ cd0_ c0_ i0_ g0_ bopdef0_ hhadj_

* Trade data:

$loaddc s0_ xd0_ xn0_ x0_ rx0_ a0_ nd0_ dd0_ m0_ ta0_ tm0_

* Margins:

$loaddc md0_ nm0_ dm0_
```

```
gm(g) = yes$(sum((yr,r,m), (nm0_(yr,r,g,m) + dm0_(yr,r,g,m))) or sum((yr,r,m),
md0_(yr,r,m,g)));

parameter   ys0(r,g,s)  Sectoral supply,
            id0(r,s,g)  Intermediate demand,
            ld0(r,s)    Labor demand,
            kd0(r,s)    Capital demand,
            m0(r,s)     Imports,
            x0(r,s)     Exports of goods and services,
            rx0(r,s)    Re-exports of goods and services,
            md0(r,m,s)  Total margin demand,
            nm0(r,g,m)  Margin demand from national market,
            dm0(r,g,m)  Margin supply from local market,
            s0(r,s)     Aggregate supply,
            a0(r,s)     Armington supply,
            ta0(r,s)    Benchmark tax net subsidy rate on intermediate demand,
            tm0(r,s)    Benchmark import tariff,
            ta(r,s)     Scenario tax rate,
            tm(r,s)     Scenario duty,
            cd0(r,s)    Final demand,
            c0(r)       Aggregate final demand,
            yh0(r,s)    Household production,
            bopdef0(r)  Balance of payments,
            hhadj(r)    Household adjustment,
            g0(r,s)     Government demand,
            i0(r,s)     Investment demand,
            xn0(r,g)    Regional supply to national market,
            xd0(r,g)    Regional supply to local market,
            dd0(r,g)    Regional demand from local market,
            nd0(r,g)    Regional demand from national market;

ys0(r,g,s) = ys0_('%year%',r,g,s);
id0(r,s,g) = id0_('%year%',r,s,g);
ld0(r,s) = ld0_('%year%',r,s);
kd0(r,s) = kd0_('%year%',r,s);
m0(r,g) = m0_('%year%',r,g);
x0(r,g) = x0_('%year%',r,g);
rx0(r,g) = rx0_('%year%',r,g);
md0(r,m,gm) = md0_('%year%',r,m,gm);
nm0(r,gm,m) = nm0_('%year%',r,gm,m);
dm0(r,gm,m) = dm0_('%year%',r,gm,m);
s0(r,g) = s0_('%year%',r,g);
a0(r,g) = a0_('%year%',r,g);
ta0(r,g) = ta0_('%year%',r,g);
tm0(r,g) = tm0_('%year%',r,g);
cd0(r,g) = cd0_('%year%',r,g);
c0(r) = c0_('%year%',r);
yh0(r,g) = yh0_('%year%',r,g);
bopdef0(r) = bopdef0_('%year%',r);
g0(r,g) = g0_('%year%',r,g);
i0(r,g) = i0_('%year%',r,g);
xn0(r,g) = xn0_('%year%',r,g);
xd0(r,g) = xd0_('%year%',r,g);
dd0(r,g) = dd0_('%year%',r,g);
nd0(r,g) = nd0_('%year%',r,g);
hhadj(r) = hhadj_('%year%',r);

ta(r,g) = ta0(r,g);
tm(r,g) = tm0(r,g);
```

```
sets  y_(r,s)      Production zero profit indicator,
      x_(r,g)      Disposition zero profit indicator,
      a_(r,g)      Absorption zero profit indicator,
      pa_(r,g)     Absorption market indicator,
      py_(r,g)     Output market indicator,
      pd_(r,g)     Regional market indicator,
      pk_(r,s)     Capital market indicator;

y_(r,s) = (sum(g, ys0(r,s,g))>0);
x_(r,g) = s0(r,g);
a_(r,g) = (a0(r,g) + rx0(r,g));
pa_(r,g) = a0(r,g);
py_(r,g) = s0(r,g);
pd_(r,g) = xd0(r,g);
pk_(r,s) = kd0(r,s);

$ontext
$model:mge

$sectors:
      Y(r,s)$y_(r,s)    !     Production
      X(r,g)$x_(r,g)    !     Disposition
      A(r,g)$a_(r,g)    !     Absorption
      C(r)              !     Aggregate final demand
      MS(r,m)           !     Margin supply

$commodities:
      PA(r,g)$pa_(r,g)  !     Regional market (input)
      PY(r,g)$py_(r,g)  !     Regional market (output)
      PD(r,g)$pd_(r,g)  !     Local market price
      PN(g)             !     National market
      PL(r)             !     Wage rate
      PK(r,s)$pk_(r,s)  !     Rental rate of capital
      PM(r,m)           !     Margin price
      PC(r)             !     Consumer price index
      PFX               !     Foreign exchange

$consumer:
      RA(r)             !     Representative agent

$prod:Y(r,s)$y_(r,s) s:0 va:1
      o:PY(r,g)   q:ys0(r,s,g)
      i:PA(r,g)   q:id0(r,g,s)
      i:PL(r)     q:ld0(r,s)  va:
      i:PK(r,s)   q:kd0(r,s)  va:

$prod:X(r,g)$x_(r,g) t:4
      o:PFX       q:(x0(r,g)-rx0(r,g))
      o:PN(g)     q:xn0(r,g)
      o:PD(r,g)   q:xd0(r,g)
      i:PY(r,g)   q:s0(r,g)

$prod:A(r,g)$a_(r,g) s:0 dm:2 d(dm):4
      o:PA(r,g)   q:a0(r,g)         a:RA(r) t:ta(r,g) p:(1-ta0(r,g))
      o:PFX       q:rx0(r,g)
      i:PN(g)     q:nd0(r,g)  d:
      i:PD(r,g)   q:dd0(r,g)  d:
      i:PFX       q:m0(r,g)   dm:   a:RA(r) t:tm(r,g)  p:(1+tm0(r,g))
      i:PM(r,m)   q:md0(r,m,g)
```

```
$prod:MS(r,m)
      o:PM(r,m)    q:(sum(gm, md0(r,m,gm)))
      i:PN(gm)     q:nm0(r,gm,m)
      i:PD(r,gm)   q:dm0(r,gm,m)

$prod:C(r) s:1
      o:PC(r)      q:c0(r)
      i:PA(r,g)    q:cd0(r,g)

$demand:RA(r)
      d:PC(r)      q:c0(r)
      e:PY(r,g)    q:yh0(r,g)
      e:PFX        q:(bopdef0(r) + hhadj(r))
      e:PA(r,g)    q:(-g0(r,g) - i0(r,g))
      e:PL(r)      q:(sum(s,ld0(r,s)))
      e:PK(r,s)    q:kd0(r,s)

$offtext
$sysinclude mpsgeset mge

mge.workspace = 100;
mge.iterlim = 0;
$include mge.gen
solve mge using mcp;
abort$(mge.objval>1e-4) "Error in benchmark calibration with regional data.";

*     Define the corresponding MCP model

equations
      profit_Y(r,s)      Zero profit: production
      profit_X(r,g)      Zero profit: disposition
      profit_A(r,g)      Zero profit: absorption
      profit_C(r)        Zero profit: final demand
      profit_MS(r,m)     Zero profit: margin supply

      market_PA(r,g)     Market clearance: absorption
      market_PY(r,g)     Market clearance: output
      market_PD(r,g)     Market clearance: local market
      market_PN(g)       Market clearance: national market
      market_PL(r)       Market clearance: labor
      market_PK(r,s)     Market clearance: capital
      market_PM(r,m)     Market clearance: margin
      market_PC(r)       Market clearance: consumption
      market_PFX         Market clearance: foreign exchange

      income_RA(r)       Income balance: representative agent;


parameter   alpha(r,s)  Labor value share;

alpha(r,s)$ld0(r,s) = ld0(r,s)/(ld0(r,s)+kd0(r,s));

$macro CVA(r,s)    (PL(r)**alpha(r,s)*PK(r,s)**(1-alpha(r,s)))
$macro AL(r,s)     (ld0(r,s)*cva(r,s)/PL(r))
$macro AK(r,s)     (kd0(r,s)*cva(r,s)/PK(r,s))

parameter   alphax(r,g) Export value share
            alphad(r,g) Local supply share
            alphan(r,g) National supply share;
```

```
alphax(r,g)$(x0(r,g)-rx0(r,g)) = (x0(r,g)-rx0(r,g))/s0(r,g);
alphad(r,g)$xd0(r,g) = xd0(r,g)/s0(r,g);
alphan(r,g)$xn0(r,g) = xn0(r,g)/s0(r,g);

$macro RX(r,g)     ((alphax(r,g)*PFX**5+alphan(r,g)*PN(g)**5+alphad(r,g)*PD(r,g)
**5)**(1/5))
$macro AX(r,g)     ((x0(r,g)-rx0(r,g))*(PFX/RX(r,g))**4)
$macro AN(r,g)     (xn0(r,g)*(PN(g)/RX(r,g))**4)
$macro AD(r,g)     (xd0(r,g)*(PD(r,g)/RX(r,g))**4)

parameter   thetan(r,g) National share of domestic absorption
            thetam(r,g) Domestic share of absorption;

thetan(r,g)$nd0(r,g) = nd0(r,g)/(nd0(r,g)+dd0(r,g));
thetam(r,g)$m0(r,g) = (1+tm0(r,g))*m0(r,g)/(nd0(r,g)+dd0(r,g)+m0(r,g)*(1+tm0(r,
g)));

$macro CDN(r,g)    ((thetan(r,g)*PN(g)**(1-2)+(1-thetan(r,g))*PD(r,g)**(1-2))
**(1/(1-2)))
$macro CDM(r,g)    (((1-thetam(r,g))*CDN(r,g)**(1-4)+thetam(r,g)*(PFX*(1+tm(r,g)
)/(1+tm0(r,g)))**(1-4))**(1/(1-4)))

$macro DN(r,g)     (nd0(r,g)*(CDN(r,g)/PN(g))**2*(CDM(r,g)/CDN(r,g))**4)
$macro DD(r,g)     (dd0(r,g)*(CDN(r,g)/PD(r,g))**2*(CDM(r,g)/CDN(r,g))**4)
$macro MD(r,g)     (m0(r,g)*(CDM(r,g)*(1+tm0(r,g))/(PFX*(1+tm(r,g))))**4)

$macro CD(r,g) (cd0(r,g)*PC(r)/PA(r,g))

profit_Y(y_(r,s))..      sum(g,PA(r,g)*id0(r,g,s)) + PL(r)*AL(r,s) + PK(r,s)*AK(
r,s) =e= sum(g, PY(r,g)*ys0(r,s,g));

profit_X(x_(r,g))..      PY(r,g)*s0(r,g) =e= PFX*AX(r,g) + PN(g)*AN(r,g) + PD(r,
g)*AD(r,g);

profit_A(a_(r,g))..      PN(g)*DN(r,g) + PD(r,g)*DD(r,g) + PFX*(1+tm(r,g))*MD(r,
g) + sum(m,PM(r,m)*md0(r,m,g)) =e= PA(r,g)*(1-ta(r,g))*a0(r,g) + PFX*rx0(r,g);

profit_C(r)..            sum(g, PA(r,g)*CD(r,g)) =e= PC(r)*c0(r);

profit_MS(r,m)..         sum(gm, PN(gm)*nm0(r,gm,m) + PD(r,gm)*dm0(r,gm,m)) =e=
PM(r,m)*sum(gm,md0(r,m,gm));

market_PA(pa_(r,g))..    A(r,g)*a0(r,g) =e= g0(r,g) + i0(r,g) + C(r)*CD(r,g) +
sum(y_(r,s), Y(r,s)*id0(r,g,s));

market_PY(py_(r,g))..    sum(y_(r,s), Y(r,s)*ys0(r,s,g)) + yh0(r,g) =e= X(r,g)*
s0(r,g);

market_PD(pd_(r,g))..    X(r,g)*AD(r,g) =e= A(r,g)*DD(r,g) + sum(m, MS(r,m)*dm0(
r,g,m))$gm(g);

market_PN(g)..           sum(r,X(r,g)*AN(r,g)) =e= sum(r, A(r,g)*DN(r,g)) + sum
((r,m), MS(r,m)*nm0(r,g,m))$gm(g);

market_PL(r)..           sum(s,ld0(r,s)) =e= sum(s, Y(r,s)*AL(r,s));

market_PK(pk_(r,s))..    kd0(r,s) =e= Y(r,s)*AK(r,s);

market_PM(r,m)..         MS(r,m)*sum(gm, md0(r,m,gm)) =e= sum(g, A(r,g)*md0(r,m,
g));
```

```
market_PC(r)..          C(r)*c0(r) =e= RA(r)/PC(r);

market_PFX..            sum(r, bopdef0(r)) + sum((r,g),X(r,g)*AX(r,g)) + sum(a_
(r,g), A(r,g)*rx0(r,g)) =e= sum((r,g),A(r,g)*MD(r,g));

income_RA(r)..          RA(r) =e= sum(g,PY(r,g)*yh0(r,g)) + PFX*(bopdef0(r)+
hhadj(r)) - sum(g, PA(r,g)*(g0(r,g)+i0(r,g))) + PL(r)*sum(s,ld0(r,s)) + sum(pk_
(r,s), PK(r,s)*kd0(r,s)) + sum(a_(r,g), A(r,g)*( MD(r,g)*PFX*tm(r,g) + a0(r,g)*
PA(r,g)*ta(r,g) ));

model mcp /
      profit_Y.Y, profit_X.X, profit_A.A, profit_C.C, profit_MS.MS,

      market_PA.PA, market_PY.PY, market_PD.PD, market_PN.PN,
      market_PL.PL, market_PK.PK, market_PM.PM, market_PC.PC,
      market_PFX.PFX,

      income_RA.RA /;

PK.FX(r,s)$(not kd0(r,s)) = 1;
PA.FX(r,g)$(not a0(r,g)) = 1;
PY.FX(r,g)$(not s0(r,g)) = 1;
PD.FX(r,g)$(not xd0(r,g)) = 1;
RA.L(r) = c0(r);

mcp.iterlim = 0;
solve mcp using mcp;
```

Appendix D. Core Model Policy Shock Results

Table D.1. Carbon Emissions and Leakage Rates: Gravity Trade and Core Production Structure (%)

		CA		**RGGI**		**CA-RGGI**		**History**		**State Alliance**		**Carbon Center**		**Climate Mayors**	
		Trade	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*
State Emissions % Change	*Alaska*	0.6	0.6	0.6	0.6	1.2	1.3	1.5	1.6	3.7	4.1	5.1	5.5	-31.5	-20.0
	Alabama	2.3	2.3	3.0	3.3	5.7	6.0	6.8	7.1	17.3	19.3	25.1	27.5	41.2	45.6
	Arkansas	2.2	2.2	2.5	2.8	5.0	5.3	6.0	6.4	15.2	16.9	-38.4	-20.0	-34.3	-20.0
	Arizona	3.2	3.2	1.9	2.1	5.2	5.6	6.4	7.0	13.0	15.3	17.5	20.4	-22.2	-20.0
	California	-20.0	-20.0	1.1	1.3	-17.7	-20.0	-18.8	-20.0	-11.4	-20.0	-10.1	-20.0	-8.2	-20.0
	Colorado	2.0	2.0	1.7	1.9	3.8	4.1	4.6	5.0	-42.1	-20.0	-41.8	-20.0	-41.5	-20.0
	Connecticut	0.9	0.9	-10.9	-20.0	-13.3	-20.0	-14.6	-20.0	-7.0	-20.0	-5.8	-20.0	-4.9	-20.0
	D.C.	1.2	1.2	0.6	0.7	1.9	2.0	2.3	2.5	2.9	4.1	-2.4	-20.0	-2.4	-20.0
	Delaware	1.9	1.9	-35.8	-20.0	-39.1	-20.0	-40.0	-20.0	-27.6	-20.0	-25.3	-20.0	-25.0	-20.0
	Florida	1.8	1.8	2.1	2.4	4.2	4.5	5.0	5.3	11.2	13.0	-32.2	-20.0	-28.6	-20.0
	Georgia	1.5	1.5	2.0	2.2	3.7	3.9	4.4	4.6	11.1	12.4	15.8	17.4	25.5	28.2
	Hawaii	2.6	2.6	1.8	2.0	4.6	4.9	5.6	6.1	-35.9	-20.0	-35.5	-20.0	-34.9	-20.0
	Iowa	1.4	1.4	1.4	1.6	3.0	3.2	3.7	3.9	9.0	10.2	11.8	13.5	19.2	21.9
	Idaho	2.1	2.1	0.9	1.0	3.1	3.4	4.1	4.5	5.7	7.7	7.3	9.9	11.6	15.2
	Illinois	1.6	1.6	1.7	1.9	3.5	3.7	4.2	4.5	-15.0	-20.0	-12.5	-20.0	-9.1	-20.0
	Indiana	1.5	1.5	2.0	2.2	3.7	3.9	4.4	4.6	12.5	13.6	16.4	18.0	26.1	28.8
	Kansas	1.8	1.8	1.8	2.0	3.8	4.0	4.6	4.9	11.5	12.9	15.5	17.4	26.3	29.3
	Kentucky	1.6	1.6	2.3	2.5	4.1	4.3	4.9	5.1	12.9	14.2	17.0	18.9	26.7	29.9
	Louisiana	0.5	0.5	0.5	0.6	1.1	1.2	1.3	1.4	2.9	3.4	3.9	4.5	6.8	7.6
	Massachusetts	1.5	1.5	-26.4	-20.0	-29.7	-20.0	-30.6	-20.0	-17.8	-20.0	-15.7	-20.0	-15.0	-20.0
	Maryland	1.2	1.2	-36.1	-20.0	-37.5	-20.0	-38.3	-20.0	-23.9	-20.0	-20.6	-20.0	-19.8	-20.0
	Maine	2.0	2.0	-21.7	-20.0	-24.1	-20.0	-25.3	-20.0	-19.5	-20.0	-19.1	-20.0	-19.8	-20.0
	Michigan	1.7	1.7	2.2	2.5	4.3	4.6	5.1	5.4	-29.3	-20.0	-26.8	-20.0	-26.0	-20.0
	Minnesota	1.8	1.8	1.8	2.0	3.8	4.1	4.6	5.0	-23.4	-20.0	-21.1	-20.0	-19.1	-20.0
	Missouri	1.7	1.7	2.1	2.3	4.0	4.3	4.8	5.0	13.5	14.7	18.1	19.7	30.0	32.8
	Mississippi	2.4	2.4	2.5	2.9	5.3	5.7	6.5	6.9	14.2	16.7	19.8	23.0	33.5	38.7
	Montana	2.2	2.2	2.2	2.4	4.5	4.8	5.6	6.1	14.6	16.1	19.8	21.7	33.6	36.8
	North Carolina	1.5	1.5	2.1	2.4	3.9	4.1	4.6	4.8	-32.2	-20.0	-27.2	-20.0	-25.4	-20.0
	North Dakota	2.4	2.4	2.8	3.1	5.5	5.9	6.6	7.0	18.7	20.3	25.2	27.4	41.9	45.7
	Nebraska	0.6	0.6	0.4	0.5	1.1	1.2	1.4	1.5	2.3	3.0	3.1	3.8	5.1	6.2
	New Hampshire	2.2	2.2	-19.9	-20.0	-22.1	-20.0	-23.2	-20.0	-16.4	-20.0	-15.4	-20.0	-15.0	-20.0
	New Jersey	0.8	0.8	1.6	1.8	2.7	2.8	3.1	3.2	-8.3	-20.0	-7.0	-20.0	-6.1	-20.0
	New Mexico	2.4	2.4	2.4	2.6	5.0	5.3	6.0	6.4	-52.9	-20.0	-52.7	-20.0	-53.6	-20.0
	Nevada	3.0	3.0	1.5	1.6	4.6	5.0	5.9	6.4	10.4	12.7	-17.3	-20.0	-13.0	-20.0
	New York	1.2	1.2	-11.1	-20.0	-13.2	-20.0	-14.4	-20.0	-6.5	-20.0	-4.8	-20.0	-2.6	-20.0
	Ohio	1.4	1.4	2.0	2.2	3.6	3.9	4.3	4.5	10.5	12.1	13.8	16.0	22.1	25.4
	Oklahoma	1.6	1.6	1.9	2.1	3.7	3.9	4.4	4.6	12.2	13.2	17.4	18.4	31.8	33.8
	Oregon	2.8	2.8	1.1	1.3	4.0	4.4	-15.1	-20.0	-8.4	-20.0	-7.0	-20.0	-5.0	-20.0
	Pennsylvania	1.3	1.3	2.4	2.8	4.1	4.4	4.8	5.0	10.9	12.8	14.3	16.8	22.8	26.4
	Rhode Island	1.5	1.5	-35.4	-20.0	-36.8	-20.0	-37.5	-20.0	-23.3	-20.0	-19.7	-20.0	-19.1	-20.0
	South Carolina	2.2	2.2	2.7	3.1	5.4	5.7	6.5	6.8	14.1	16.7	-22.1	-20.0	-19.3	-20.0
	South Dakota	2.1	2.1	1.4	1.7	3.8	4.1	4.8	5.2	8.3	10.5	11.0	13.9	17.9	22.3
	Tennessee	1.1	1.1	1.3	1.5	2.6	2.7	3.1	3.2	7.2	8.1	9.9	11.1	-34.5	-20.0
	Texas	1.5	1.5	1.2	1.4	2.9	3.1	3.5	3.8	7.8	9.1	10.6	12.2	-22.8	-20.0
	Utah	2.5	2.5	1.8	2.0	4.4	4.7	5.4	5.9	12.1	13.7	16.2	18.3	26.9	30.2
	Virginia	1.2	1.2	1.9	2.2	3.4	3.6	4.0	4.2	-26.5	-20.0	-22.1	-20.0	-20.6	-20.0
	Vermont	2.2	2.2	-20.0	-20.0	-22.1	-20.0	-23.1	-20.0	-18.7	-20.0	-18.7	-20.0	-20.4	-20.0
	Washington	1.5	1.5	0.6	0.7	2.2	2.5	-12.0	-20.0	-7.0	-20.0	-6.4	-20.0	-5.6	-20.0
	Wisconsin	1.4	1.4	1.6	1.8	3.3	3.5	4.0	4.2	-37.6	-20.0	-34.7	-20.0	-34.6	-20.0
	West Virginia	1.8	1.8	4.4	4.6	6.8	6.8	7.8	7.8	22.1	23.5	29.0	31.4	45.1	49.2
	Wyoming	2.2	2.2	2.7	2.8	5.1	5.3	6.1	6.5	18.7	19.3	25.1	26.1	42.0	44.3
National Emissions (% Change)		0.1	0.1	0.2	0.4	0.3	0.6	0.5	0.7	-0.3	0.6	-0.6	0.4	-2.7	-1.6
Leakage (%)		109.0	109.0	114.3	128.5	112.5	119.8	114.4	121.0	95.9	108.6	92.8	104.3	78.2	87.1

Table D.2. Carbon Emissions and Leakage Rates: Pooled National Market and Core Production Structure (%)

		CA		**RGGI**		**CA-RGGI**		**History**		**State Alliance**		**Carbon Center**		**Climate Mayors**	
		Trade	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*
State Emissions % Change	*Alaska*	0.4	0.4	0.4	0.5	0.9	0.9	1.0	1.1	3.3	3.6	4.6	4.9	-31.0	-20.0
	Alabama	3.1	3.1	3.2	3.7	6.9	7.5	8.2	8.9	20.2	23.4	28.3	32.9	48.7	56.8
	Arkansas	2.6	2.6	2.7	3.1	5.8	6.2	6.9	7.4	17.0	19.5	-46.0	-20.0	-44.4	-20.0
	Arizona	1.4	1.4	1.6	1.9	3.4	3.6	4.0	4.3	10.7	12.0	14.8	16.6	-18.2	-20.0
	California	-20.0	-20.0	1.5	1.7	-16.7	-20.0	-17.5	-20.0	-12.0	-20.0	-10.4	-20.0	-8.8	-20.0
	Colorado	1.1	1.1	1.3	1.5	2.7	2.9	3.2	3.4	-41.7	-20.0	-41.2	-20.0	-40.6	-20.0
	Connecticut	1.0	1.0	-9.8	-20.0	-10.9	-20.0	-11.5	-20.0	-6.8	-20.0	-5.4	-20.0	-3.8	-20.0
	D.C.	0.8	0.8	0.8	0.9	1.6	1.8	1.9	2.1	3.3	4.2	-1.2	-20.0	-0.1	-20.0
	Delaware	2.5	2.5	-38.5	-20.0	-45.1	-20.0	-48.6	-20.0	-33.9	-20.0	-31.7	-20.0	-31.5	-20.0
	Florida	1.9	1.9	2.0	2.3	4.2	4.6	5.0	5.4	11.4	13.3	-26.0	-20.0	-22.9	-20.0
	Georgia	1.3	1.3	1.5	1.7	3.1	3.3	3.7	3.9	9.6	10.7	13.3	14.9	22.3	25.2
	Hawaii	1.2	1.2	1.4	1.6	2.9	3.1	3.4	3.6	-34.7	-20.0	-34.0	-20.0	-33.0	-20.0
	Iowa	1.5	1.5	1.5	1.7	3.2	3.5	3.8	4.1	8.8	10.2	12.1	14.2	20.5	23.8
	Idaho	1.3	1.3	1.2	1.3	2.6	2.9	3.1	3.5	5.7	7.1	7.8	9.6	12.8	15.5
	Illinois	1.6	1.6	1.7	1.9	3.6	3.9	4.3	4.6	-14.2	-20.0	-11.4	-20.0	-7.0	-20.0
	Indiana	1.5	1.5	1.6	1.9	3.4	3.7	4.1	4.3	10.8	12.1	14.9	16.8	25.2	28.3
	Kansas	1.5	1.5	1.5	1.8	3.3	3.5	3.9	4.2	10.1	11.4	13.9	15.8	23.8	27.0
	Kentucky	2.0	2.0	2.1	2.4	4.5	4.9	5.4	5.8	13.0	15.0	18.0	20.8	30.4	35.3
	Louisiana	0.4	0.4	0.4	0.5	0.9	1.0	1.1	1.2	2.6	3.0	3.6	4.1	6.2	7.0
	Massachusetts	2.4	2.4	-25.8	-20.0	-29.6	-20.0	-31.4	-20.0	-20.8	-20.0	-18.3	-20.0	-16.7	-20.0
	Maryland	1.2	1.2	-23.7	-20.0	-31.2	-20.0	-38.2	-20.0	-18.2	-20.0	-15.7	-20.0	-13.7	-20.0
	Maine	4.8	4.8	-44.8	-20.0	-46.8	-20.0	-47.5	-20.0	-43.8	-20.0	-43.3	-20.0	-44.2	-20.0
	Michigan	2.4	2.4	2.4	2.8	5.2	5.7	6.2	6.8	-32.8	-20.0	-30.1	-20.0	-28.8	-20.0
	Minnesota	1.7	1.7	1.7	2.0	3.7	4.0	4.4	4.8	-22.1	-20.0	-19.5	-20.0	-17.1	-20.0
	Missouri	1.2	1.2	1.5	1.7	3.0	3.2	3.6	3.7	10.4	11.3	14.4	15.7	24.4	26.9
	Mississippi	4.7	4.7	4.3	5.0	9.9	10.9	11.8	13.1	24.8	30.7	35.3	43.7	62.0	76.8
	Montana	1.1	1.1	1.5	1.7	2.9	3.1	3.5	3.6	11.4	12.1	15.8	17.0	27.5	29.9
	North Carolina	1.5	1.5	1.6	1.9	3.4	3.7	4.1	4.4	-27.2	-20.0	-24.1	-20.0	-22.3	-20.0
	North Dakota	2.0	2.0	2.1	2.7	4.5	5.1	5.4	5.9	14.8	16.8	20.9	23.5	36.1	40.2
	Nebraska	0.5	0.5	0.4	0.5	0.9	1.0	1.1	1.2	2.2	2.6	3.0	3.6	4.9	5.8
	New Hampshire	4.6	4.6	-39.9	-20.0	-41.8	-20.0	-42.5	-20.0	-37.7	-20.0	-36.5	-20.0	-36.4	-20.0
	New Jersey	0.9	0.9	0.8	1.0	1.8	2.0	2.2	2.4	-6.7	-20.0	-5.3	-20.0	-3.5	-20.0
	New Mexico	1.4	1.4	1.8	2.1	3.6	3.9	4.4	4.5	-54.2	-20.0	-53.9	-20.0	-54.8	-20.0
	Nevada	1.6	1.6	1.6	1.9	3.5	3.8	4.1	4.5	9.7	11.3	-13.4	-20.0	-9.6	-20.0
	New York	1.5	1.5	-11.3	-20.0	-12.2	-20.0	-12.7	-20.0	-6.8	-20.0	-4.6	-20.0	-1.2	-20.0
	Ohio	1.6	1.6	1.6	1.8	3.4	3.7	4.1	4.4	9.8	11.3	13.5	15.7	22.8	26.4
	Oklahoma	1.1	1.1	1.4	1.6	2.8	3.0	3.4	3.5	10.7	11.4	14.9	16.1	26.0	28.4
	Oregon	1.8	1.8	1.6	1.8	3.6	3.9	-17.0	-20.0	-11.0	-20.0	-9.1	-20.0	-7.0	-20.0
	Pennsylvania	1.3	1.3	1.4	1.6	2.9	3.1	3.5	3.7	9.1	10.3	12.6	14.2	21.5	24.3
	Rhode Island	2.2	2.2	-29.7	-20.0	-44.9	-20.0	-46.3	-20.0	-23.9	-20.0	-21.4	-20.0	-20.3	-20.0
	South Carolina	4.7	4.7	4.4	5.0	9.9	11.0	11.9	13.2	24.6	30.6	-40.4	-20.0	-38.0	-20.0
	South Dakota	2.4	2.4	2.2	2.5	4.9	5.4	5.8	6.4	11.3	13.9	15.7	19.4	26.5	32.3
	Tennessee	0.9	0.9	0.9	1.1	2.0	2.2	2.4	2.5	5.9	6.7	8.1	9.1	-36.5	-20.0
	Texas	1.3	1.3	1.3	1.5	2.9	3.1	3.4	3.7	8.0	9.4	11.1	13.0	-23.3	-20.0
	Utah	1.3	1.3	1.5	1.7	3.1	3.3	3.7	3.9	10.0	11.1	13.8	15.4	23.1	25.9
	Virginia	1.2	1.2	1.3	1.5	2.7	2.9	3.2	3.4	-19.8	-20.0	-17.0	-20.0	-14.8	-20.0
	Vermont	4.8	4.8	-43.4	-20.0	-45.6	-20.0	-46.4	-20.0	-42.8	-20.0	-42.5	-20.0	-44.3	-20.0
	Washington	0.8	0.8	0.7	0.8	1.6	1.7	-9.1	-20.0	-5.9	-20.0	-5.0	-20.0	-4.1	-20.0
	Wisconsin	1.6	1.6	1.6	1.8	3.4	3.7	4.1	4.4	-39.3	-20.0	-34.0	-20.0	-35.2	-20.0
	West Virginia	1.9	1.9	2.5	2.9	5.0	5.3	6.0	6.2	18.5	19.8	25.4	27.6	43.0	47.1
	Wyoming	1.3	1.3	1.8	2.1	3.5	3.7	4.3	4.2	14.8	15.4	20.4	21.4	34.8	37.2
National Emissions (% Change)		0.1	0.1	0.1	0.3	0.2	0.4	0.3	0.5	-0.4	0.5	-0.9	0.2	-2.7	-1.4
Leakage (%)		107.9	107.9	104.0	120.6	106.6	115.6	108.1	116.2	93.7	107.4	89.8	102.5	78.1	88.9

Table D.3. Per Capita Equivalent Variation: Gravity Trade and Core Production Structure ($ per capita)

	CA		**RGGI**		**CA-RGGI**		**History**		**State Alliance**		**Carbon Center**		**Climate Mayors**	
	Trade	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*
Alaska	234.3	234.3	131.0	174.9	397.1	444.8	502.9	550.7	708.7	1012.0	963.4	1359.2	131.9	672.8
Alabama	-2.9	-2.9	31.8	34.4	38.6	37.7	47.3	45.9	199.3	214.5	253.9	300.2	541.0	659.9
Arkansas	-5.3	-5.3	31.9	37.6	38.6	38.3	52.6	52.8	173.1	193.4	197.6	-87.0	-454.6	-694.7
Arizona	-169.8	-169.8	8.4	9.0	-145.4	-169.7	-165.4	-184.5	-91.6	-183.3	-53.0	-150.3	-645.9	-894.3
California	-319.0	-319.0	-38.4	-42.0	-387.6	-399.1	-462.2	-488.0	-551.3	-704.8	-680.0	-888.9	-1056.6	-1357.3
Colorado	-63.1	-63.1	-2.1	-1.7	-58.9	-66.9	-75.7	-87.8	-84.2	-369.0	-162.5	-448.4	-436.7	-789.0
Connecticut	-57.4	-57.4	-364.2	-449.7	-508.4	-559.1	-566.4	-601.5	-626.4	-929.7	-731.8	-1115.6	-1104.5	-1644.8
D.C.	-345.4	-345.4	-308.6	-341.3	-706.7	-737.9	-847.8	-875.7	-1492.4	-1905.9	-2258.5	-3075.8	-4079.1	-5216.2
Delaware	-135.0	-135.0	52.1	-137.8	18.0	-308.6	36.7	-359.4	-427.5	-672.6	-653.6	-902.9	-1223.4	-1579.5
Florida	-4.8	-4.8	-29.1	-27.1	-37.9	-32.0	-43.5	-36.5	-83.2	-80.3	-273.2	-378.7	-495.1	-611.2
Georgia	-8.7	-8.7	-3.9	-2.4	-9.0	-8.6	-9.5	-9.8	-64.0	-49.3	-202.5	-164.4	-285.6	-222.9
Hawaii	-79.6	-79.6	3.0	6.8	-67.3	-71.3	-106.2	-120.6	-233.3	-395.3	-271.8	-435.4	-541.5	-711.0
Iowa	-37.9	-37.9	5.6	4.4	-24.7	-33.2	-27.9	-38.2	-163.7	-200.3	-166.0	-212.1	-202.2	-262.0
Idaho	-160.9	-160.9	4.5	6.9	-139.4	-163.4	-202.0	-258.2	-170.8	-318.6	-190.3	-351.1	-320.0	-525.1
Illinois	-6.9	-6.9	-16.8	-17.9	-24.1	-22.8	-27.7	-25.9	-613.5	-622.4	-723.6	-757.9	-1051.9	-1126.3
Indiana	-9.2	-9.2	-15.6	-19.3	-24.7	-28.4	-26.3	-29.6	-279.3	-311.6	-317.0	-370.1	-354.0	-438.7
Kansas	-32.2	-32.2	19.5	23.3	-1.3	-5.8	3.6	-1.4	15.1	28.2	50.1	79.1	47.0	119.9
Kentucky	-0.5	-0.5	11.7	14.7	18.7	18.5	27.0	26.4	-50.0	-36.0	-50.2	-26.7	-79.4	-21.2
Louisiana	-0.3	-0.3	-14.1	-13.2	-13.1	-11.4	-7.4	-2.8	-55.6	-31.6	-113.6	-74.4	-566.1	-483.1
Massachusetts	-69.1	-69.1	-189.7	-329.2	-266.6	-438.6	-297.1	-485.9	-608.1	-886.1	-766.4	-1107.4	-1220.7	-1702.3
Maryland	-48.6	-48.6	16.2	-117.4	24.8	-183.6	43.8	-208.7	-406.9	-517.8	-541.8	-670.7	-884.1	-1069.4
Maine	-56.0	-56.0	87.6	38.3	93.1	-33.6	118.0	-53.3	-58.4	-128.1	-114.9	-187.5	-242.7	-374.0
Michigan	-25.0	-25.0	-42.0	-51.6	-75.5	-80.9	-91.3	-95.7	-380.0	-524.4	-514.8	-667.8	-797.8	-1019.8
Minnesota	-34.8	-34.8	-18.9	-22.4	-53.1	-59.0	-66.5	-75.2	-460.8	-531.3	-587.2	-663.2	-936.7	-1049.4
Missouri	-16.9	-16.9	3.3	4.1	-8.5	-11.6	-8.9	-13.1	-80.6	-96.7	-109.3	-118.4	-158.9	-164.1
Mississippi	-24.3	-24.3	12.7	15.3	-3.6	-6.5	-0.4	-3.1	56.4	59.0	73.0	93.9	117.5	184.4
Montana	-82.3	-82.3	63.8	80.6	7.8	1.5	8.1	-8.8	240.1	218.2	389.7	385.4	790.6	833.5
North Carolina	-34.9	-34.9	-39.7	-47.2	-80.5	-86.3	-96.8	-102.3	-306.5	-454.3	-577.5	-709.2	-969.2	-1158.0
North Dakota	-21.3	-21.3	129.9	157.0	149.8	154.1	185.9	183.4	568.3	621.1	878.7	979.8	1742.8	1982.1
Nebraska	71.4	71.4	81.6	102.0	177.4	190.4	230.6	245.6	314.6	454.3	432.0	620.7	706.2	996.8
New Hampshire	-79.0	-79.0	-2.3	-16.5	-55.4	-117.6	-56.3	-148.6	-200.2	-264.8	-277.6	-348.7	-516.9	-629.3
New Jersey	-13.4	-13.4	-145.1	-247.2	-202.0	-279.0	-230.4	-292.2	-553.7	-773.3	-632.8	-912.4	-884.1	-1263.9
New Mexico	-118.8	-118.8	31.0	37.9	-70.2	-83.1	-76.3	-87.3	553.2	-237.5	540.2	-259.9	16.2	-960.1
Nevada	-504.8	-504.8	-7.2	-11.1	-472.9	-547.4	-533.2	-582.4	-407.4	-701.3	-865.7	-1288.1	-1353.3	-1946.3
New York	-60.7	-60.7	-338.1	-369.6	-475.1	-471.1	-534.0	-515.3	-725.8	-1004.2	-851.4	-1218.3	-1269.5	-1768.2
Ohio	-13.5	-13.5	-38.5	-44.2	-57.9	-59.6	-66.4	-66.5	-268.3	-266.9	-323.2	-333.0	-416.2	-428.7
Oklahoma	50.1	50.1	55.8	68.2	121.2	130.5	157.3	169.3	314.0	396.1	464.1	573.2	472.1	673.8
Oregon	-127.7	-127.7	4.8	4.4	-108.9	-129.7	-408.8	-468.7	-365.6	-582.1	-394.1	-650.7	-519.8	-872.0
Pennsylvania	-1.8	-1.8	-114.9	-137.4	-142.7	-146.6	-157.4	-151.0	-149.7	-244.0	-130.8	-249.3	-39.6	-168.2
Rhode Island	-99.5	-99.5	-24.5	-148.8	-85.8	-280.6	-86.4	-320.1	-366.4	-539.2	-528.6	-710.7	-976.4	-1254.2
South Carolina	-24.3	-24.3	-3.1	-6.0	-24.7	-30.5	-29.4	-35.9	-113.5	-105.6	-264.8	-321.4	-483.6	-542.6
South Dakota	-153.0	-153.0	3.9	4.8	-133.3	-156.0	-159.6	-186.0	-180.8	-283.7	-215.9	-325.1	-506.6	-647.3
Tennessee	-2.0	-2.0	-2.0	-0.4	0.0	-0.5	3.3	2.3	-106.2	-85.4	-159.9	-128.9	-450.0	-645.4
Texas	14.9	14.9	-27.3	-24.0	-16.6	-6.3	-17.3	-5.0	-55.1	-14.7	-100.1	-41.1	-1121.3	-1191.6
Utah	-146.5	-146.5	9.8	11.2	-121.3	-142.1	-146.3	-170.4	-123.1	-197.5	-105.7	-184.5	-160.1	-242.7
Virginia	-37.7	-37.7	-104.1	-91.4	-156.9	-136.5	-178.2	-154.6	-472.8	-570.2	-650.8	-752.1	-1073.5	-1225.2
Vermont	-95.4	-95.4	94.7	99.9	50.8	-10.4	62.1	-31.6	3.5	-34.5	-32.9	-71.8	-134.0	-232.2
Washington	-74.4	-74.4	-16.7	-16.9	-89.8	-96.5	-604.3	-646.8	-575.5	-817.5	-627.0	-914.6	-875.9	-1229.0
Wisconsin	-25.3	-25.3	-12.1	-15.8	-36.2	-42.4	-43.0	-50.6	-336.3	-574.8	-473.3	-723.3	-782.2	-1156.6
West Virginia	21.5	21.5	87.2	103.5	129.0	137.2	155.3	161.1	412.1	486.3	576.5	689.9	1077.5	1280.4
Wyoming	168.3	168.3	254.1	370.9	490.6	587.8	642.7	747.2	1065.7	1575.3	1668.9	2267.6	3302.9	4128.0
USA	-68.6	-68.6	-50.1	-63.0	-127.0	-141.9	-160.4	-178.0	-280.2	-374.0	-368.3	-491.0	-682.7	-864.8

Table D.4. Per Capita Equivalent Variation: Pooled National Market and Core Production Structure ($ per capita)

	CA		**RGGI**		**CA-RGGI**		**History**		**State Alliance**		**Carbon Center**		**Climate Mayors**	
	Trade	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*	*Trade*	*No Trade*
Alaska	155.2	155.2	111.8	132.0	279.2	316.6	332.5	381.4	589.9	770.5	820.0	1060.7	-832.8	-257.4
Alabama	35.3	35.3	34.7	42.2	80.8	91.1	98.6	111.0	263.2	325.6	401.1	501.3	869.6	1090.4
Arkansas	48.5	48.5	38.8	45.3	95.9	108.1	116.3	133.1	241.2	314.6	-374.2	-270.1	-476.4	-364.9
Arizona	1.3	1.3	8.1	10.7	13.0	15.1	15.1	16.8	51.4	63.8	85.3	107.3	-490.3	-529.6
California	-387.1	-387.1	-4.9	-5.3	-382.9	-438.1	-410.6	-457.3	-432.8	-602.1	-485.2	-700.4	-659.2	-947.7
Colorado	2.9	2.9	7.1	9.8	13.1	16.1	15.1	18.0	-220.5	-219.7	-263.5	-256.8	-375.2	-370.8
Connecticut	-25.9	-25.9	-263.0	-415.1	-342.4	-479.2	-371.6	-502.0	-398.8	-666.1	-453.5	-775.2	-638.6	-1052.6
D.C.	-165.0	-165.0	-110.8	-120.8	-284.5	-309.7	-345.8	-384.4	-692.0	-836.4	-1235.2	-2189.1	-2158.8	-3313.5
Delaware	-22.8	-22.8	-380.5	-295.3	-456.1	-366.7	-478.8	-392.4	-641.1	-620.0	-754.0	-765.3	-1074.7	-1137.5
Florida	10.5	10.5	12.9	16.0	27.2	31.9	32.0	37.9	54.6	81.7	-332.7	-312.5	-469.8	-469.2
Georgia	4.6	4.6	9.7	13.1	17.7	22.2	20.4	25.7	28.2	51.5	46.8	83.6	105.3	179.6
Hawaii	-3.0	-3.0	17.6	25.8	22.9	28.9	24.1	27.1	-164.8	-136.2	-175.5	-135.2	-248.3	-183.3
Iowa	22.6	22.6	18.9	21.4	46.1	51.9	56.6	65.5	107.9	147.4	164.7	225.3	365.1	486.7
Idaho	10.6	10.6	5.8	7.2	16.6	20.5	20.1	26.4	6.3	27.5	9.7	38.6	39.1	85.6
Illinois	18.4	18.4	18.1	21.9	42.7	48.9	51.8	60.0	-574.7	-690.7	-617.3	-803.8	-789.4	-1121.7
Indiana	18.3	18.3	5.0	5.3	24.1	29.1	31.6	40.7	37.3	71.1	61.4	111.0	208.9	305.4
Kansas	21.7	21.7	15.7	20.1	41.4	49.1	50.3	60.3	99.2	140.0	147.1	208.4	331.6	451.9
Kentucky	44.0	44.0	31.7	37.9	82.7	95.9	100.3	119.2	167.0	244.5	249.9	364.0	527.2	747.0
Louisiana	20.1	20.1	-20.4	-22.7	-5.8	-0.9	-2.2	7.7	-43.7	-16.8	-64.9	-31.3	36.9	92.9
Massachusetts	-24.0	-24.0	-281.7	-254.8	-359.7	-320.8	-386.6	-343.9	-474.7	-528.5	-553.3	-647.5	-807.9	-964.2
Maryland	-20.4	-20.4	-216.0	-204.0	-268.2	-245.2	-284.9	-260.8	-367.4	-399.0	-438.5	-491.8	-667.5	-759.7
Maine	23.2	23.2	-266.7	-167.4	-280.2	-189.9	-281.8	-197.7	-324.4	-239.1	-350.7	-269.3	-390.6	-320.1
Michigan	4.5	4.5	3.3	3.4	10.8	12.7	15.0	18.9	-542.7	-492.4	-627.3	-601.3	-857.7	-875.0
Minnesota	10.1	10.1	7.7	8.7	20.8	23.9	26.1	31.3	-489.1	-487.3	-546.6	-575.9	-732.4	-813.0
Missouri	7.2	7.2	6.8	8.8	15.8	19.2	19.1	23.8	29.5	48.2	46.4	74.8	124.7	180.2
Mississippi	47.5	47.5	35.5	42.3	93.5	107.2	114.3	133.3	238.1	325.6	367.5	503.3	806.0	1093.6
Montana	44.5	44.5	30.0	36.7	79.2	90.0	96.0	109.5	225.5	278.9	333.9	407.8	706.4	845.0
North Carolina	-16.1	-16.1	-8.9	-8.2	-24.6	-24.5	-29.8	-30.0	-421.0	-417.2	-510.2	-525.4	-774.2	-828.4
North Dakota	101.3	101.3	89.2	108.7	209.1	237.1	249.9	282.7	582.2	715.1	861.1	1055.2	1745.2	2112.3
Nebraska	89.4	89.4	76.1	87.5	176.2	197.1	209.8	238.3	369.0	481.6	514.2	669.1	893.8	1148.7
New Hampshire	-0.3	-0.3	-220.2	-156.3	-253.0	-198.2	-261.2	-213.1	-304.0	-273.7	-339.3	-319.1	-413.0	-410.7
New Jersey	0.1	0.1	0.4	0.2	1.3	1.7	2.0	3.2	-395.3	-680.5	-433.8	-775.7	-575.8	-1025.2
New Mexico	13.1	13.1	15.2	20.7	32.9	38.7	38.9	43.9	-75.4	-176.7	-109.8	-203.1	-152.0	-275.6
Nevada	-11.7	-11.7	1.7	2.4	-5.6	-6.3	-8.1	-9.8	-3.0	2.2	-538.2	-649.7	-772.7	-969.4
New York	-29.7	-29.7	-287.1	-434.1	-377.8	-514.3	-411.2	-542.7	-449.6	-755.2	-508.2	-892.2	-712.5	-1248.0
Ohio	11.0	11.0	4.2	4.9	16.7	20.7	21.3	28.1	15.3	42.7	29.8	71.3	113.8	196.8
Oklahoma	52.2	52.2	32.5	38.6	89.0	101.2	107.5	123.6	220.7	282.0	318.9	405.4	692.1	847.2
Oregon	15.5	15.5	11.9	13.1	29.9	33.3	-341.1	-385.1	-319.9	-475.8	-334.1	-535.0	-389.1	-661.5
Pennsylvania	11.1	11.1	8.7	10.3	23.0	26.0	28.6	32.8	75.5	96.5	121.1	155.3	299.0	376.9
Rhode Island	-13.9	-13.9	-279.3	-237.0	-340.9	-285.9	-357.0	-303.3	-428.3	-443.9	-492.6	-537.4	-701.2	-788.5
South Carolina	24.5	24.5	23.0	27.5	55.5	63.8	67.9	79.6	141.2	198.3	-479.5	-415.0	-624.5	-587.0
South Dakota	12.7	12.7	13.3	15.8	30.3	35.1	36.7	43.6	66.1	97.7	106.0	156.1	237.6	342.8
Tennessee	15.2	15.2	8.9	9.9	24.7	29.2	29.7	37.2	16.2	42.9	24.3	60.6	-451.5	-429.3
Texas	25.1	25.1	7.6	10.2	35.1	42.7	44.0	54.7	80.7	123.2	122.4	185.9	-1094.9	-1097.5
Utah	11.6	11.6	11.0	13.6	25.8	29.8	31.3	36.5	68.8	92.6	106.2	142.6	233.4	308.2
Virginia	-14.6	-14.6	-1.7	2.3	-14.0	-11.2	-18.6	-17.1	-385.6	-400.0	-459.7	-493.3	-710.2	-781.9
Vermont	17.7	17.7	-224.8	-137.5	-239.9	-157.5	-241.7	-163.9	-222.3	-152.4	-215.6	-148.4	-157.8	-90.1
Washington	-6.8	-6.8	-1.3	1.4	-6.0	-4.2	-370.0	-598.9	-354.4	-702.6	-390.5	-779.7	-515.4	-966.1
Wisconsin	12.1	12.1	7.7	8.6	21.7	25.5	27.3	33.9	-425.3	-384.1	-492.6	-458.0	-673.6	-653.7
West Virginia	60.6	60.6	52.4	64.6	124.7	141.2	150.2	169.4	372.7	456.3	556.4	678.2	1144.7	1383.6
Wyoming	209.7	209.7	147.1	191.9	376.5	440.2	446.9	522.7	900.1	1179.7	1335.0	1689.6	2602.9	3182.2
USA	-39.3	-39.3	-27.5	-34.1	-69.9	-80.0	-84.9	-98.0	-171.1	-216.3	-226.4	-287.5	-411.8	-504.0