APPENDIX — Overview of the BEAR Model

The Berkeley Energy and Resources (BEAR) model is in reality a constellation of research tools designed to elucidate economy-environment linkages in California. The schematics in Figures A.1 and A.2 describe the four generic components of the modeling facility and their interactions. This section provides a brief summary of the formal structure of the BEAR model.[1] For the purposes of this report, the 2016 California Social Accounting Matrix (SAM), was aggregated along certain dimensions. The current version of the model includes 50 activity sectors and ten households aggregated from the original California SAM. The equations of the model are completely documented elsewhere, and for the present we only discuss its salient structural components. [2]

1.1 Structure of the GCE Model

Technically, a CGE model is a system of simultaneous equations that simulate price–directed interactions between firms and households in commodity and factor markets. The role of government, capital markets, and other trading partners are also specified, with varying degrees of detail and passivity, to close the model and account for economy-wide resource allocation, production, and income determination.

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economy-wide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed–form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh

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[1] More information on the BEAR model is available at: https://policyinstitute.ucdavis.edu/uc-berkeley-energy-resources-bear-model/

[2] Roland-Holst, David. 2005. "Economic Assessment of Some California Greenhouse Gas Control Policies: Applications of the BEAR Model." In Managing Greenhouse Gas Emissions in California, ed. Michael Hanemann and Alexander Farrell, Chapter 2. University of California at Berkeley: The California Climate Change Center. January.

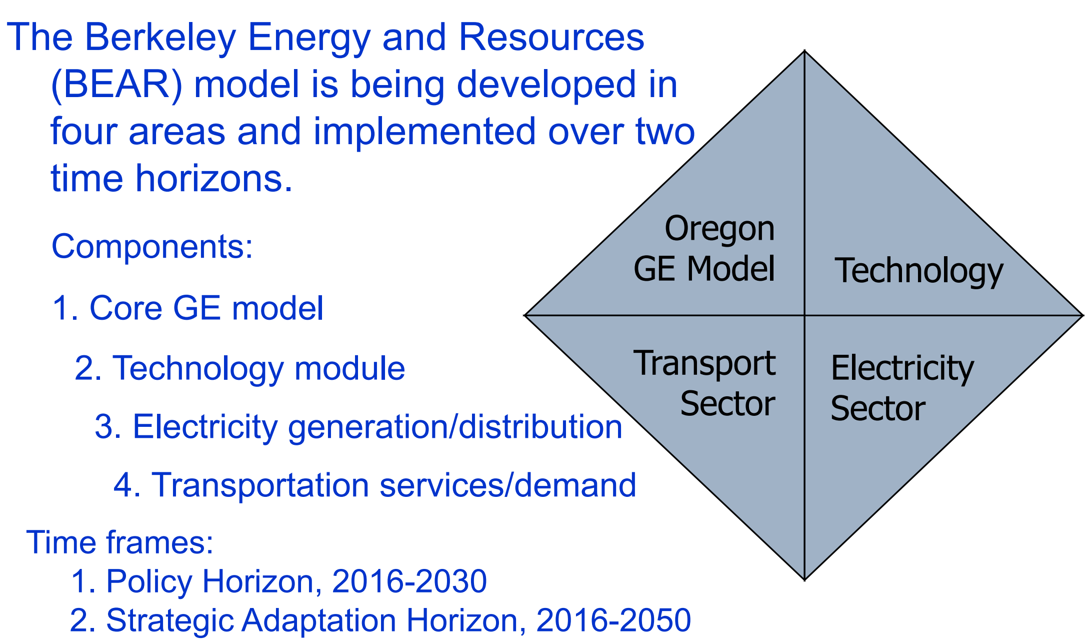
direct effects. Only a model that consistently specifies economy-wide interactions can fully assess the implications of economic policies or business strategies. In a multi–country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

The model we use for this work has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to the new California SAM estimated for the year 2012.[3] The result is a single economy model calibrated over the thirty-five-year time path from 2015 to 2050. Using the very detailed accounts of the California SAM, we include the following in the present model:

1.2 Production

All sectors are assumed to operate under constant returns to scale and cost optimization. Production technology is modeled by a nesting of constant-elasticity-of-substitution (CES) function.

Figure A.1. Component Structure of the Modeling Facility



In each period, the supply of primary factors — capital, land, and labor — is usually predetermined.[4] The model includes adjustment rigidities. An important feature is the

[3] See e.g. Meeraus et al (1992) for GAMS. Berck et al (2004) for discussion of the California SAM.
[4] Capital supply is to some extent influenced by the current period's level of investment.

distinction between old and new capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors.[5] Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply conditions in all markets.

1.3 Consumption and Closure Rule

All income generated by economic activity is assumed to be distributed to consumers. Each representative consumer allocates optimally his/her disposable income among the different commodities and saving. The consumption/saving decision is completely static: saving is treated as a "good" and its amount is determined simultaneously with the demand for the other commodities, the price of saving being set arbitrarily equal to the average price of consumer goods.

The government collects income taxes, indirect taxes on intermediate inputs, outputs and consumer expenditures. The default closure of the model assumes that the government deficit/saving is exogenously specified.[6] The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

The current account surplus (deficit) is fixed in nominal terms. The counterpart of this imbalance is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

1.4 Trade

Goods are assumed to be differentiated by region of origin. In other words, goods classified in the same sector are different according to whether they are produced domestically or imported. This assumption is frequently known as the Armington assumption. The degree of substitutability, as well as the import penetration shares are allowed to vary across commodities. The model assumes a single Armington agent. This strong assumption implies that the propensity to import and the degree of substitutability between domestic and imported goods is uniform across economic agents. This assumption reduces tremendously the dimensionality of the model. In many cases this assumption is imposed by the data. A symmetric assumption is made on the export side where domestic producers are assumed to

[5] For simplicity, it is assumed that old capital goods supplied in second-hand markets and new capital goods are homogeneous. This formulation makes it possible to introduce downward rigidities in the adjustment of capital without increasing excessively the number of equilibrium prices to be determined by the model.

[6] In the reference simulation, the real government fiscal balance converges (linearly) towards 0 by the final period of the simulation.

differentiate the domestic market and the export market. This is modeled using a Constant-Elasticity-of-Transformation (CET) function.

1.5 Dynamic Features and Calibration

The current version of the model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations about prices and quantities. Dynamics in the model originate in three sources: i) accumulation of productive capital and labor growth; ii) shifts in production technology; and iii) the putty/semi-putty specification of technology.

1.6 Capital Accumulation

In the aggregate, the basic capital accumulation function equates the current capital stock to the depreciated stock inherited from the previous period plus gross investment. However, at the sectoral level, the specific accumulation functions may differ because the demand for (old and new) capital can be less than the depreciated stock of old capital. In this case, the sector contracts over time by releasing old capital goods. Consequently, in each period, the new capital vintage available to expanding industries is equal to the sum of disinvested capital in contracting industries plus total saving generated by the economy, consistent with the closure rule of the model.

1.7 The Putty/Semi-Putty Specification

The substitution possibilities among production factors are assumed to be higher with the new than the old capital vintages — technology has a putty/semi-putty specification. Hence, when a shock to relative prices occurs (e.g. the imposition of an emissions fee), the demands for production factors adjust gradually to the long-run optimum because the substitution effects are delayed over time. The adjustment path depends on the values of the short-run elasticities of substitution and the replacement rate of capital. As the latter determines the pace at which new vintages are installed, the larger is the volume of new investment, the greater the possibility to achieve the long-run total amount of substitution among production factors.

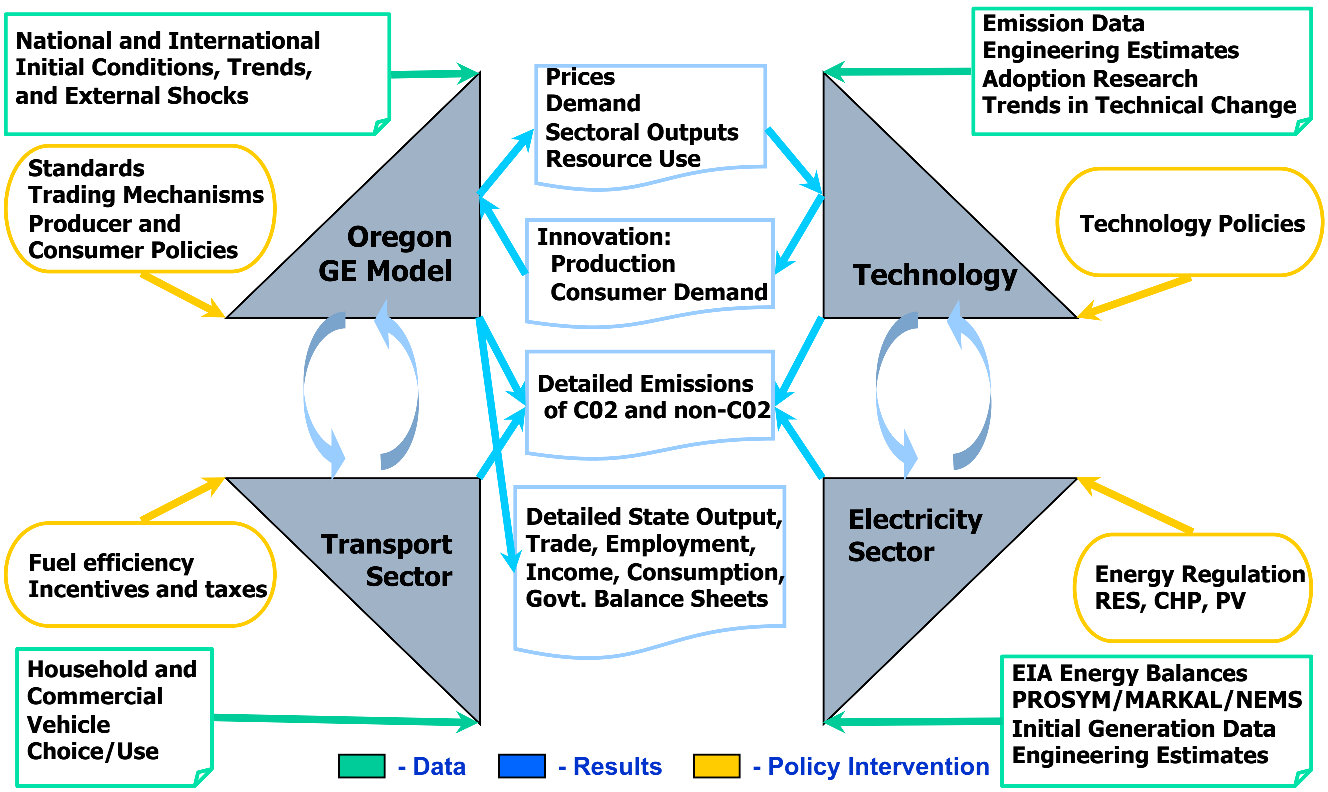
1.8 Profits, Adjustment Costs, and Expectations

Firms output and investment decisions are modeled in accordance with the innovative approach of Goulder and co-authors.[7] In particular, we allow for the possibility that firms reap windfall profits from events such as free permit distribution. Absent more detailed information

[7] Goulder, Lawrence H., Hafstead, Marc A. C. and Dworsky, Michael. Impacts of Alternative Emissions Allowance Allocation Methods Under a Federal Cap-and-trade Program. August 18, 2009. Available at SSRN: http://ssrn.com/abstract=1457155

on ownership patterns, we assume that these profits accrue to US and foreign residents in proportion to equity shares of publicly traded US corporations (16% in 2009).[8] Between California and other US residents, the shares are assumed to be proportional to GDP in GDP.

Figure A.2. Schematic Linkage Between Model Components



1.9 Dynamic calibration

The model is calibrated on exogenous growth rates of population, labor force, and GDP. In the so-called Baseline scenario, the dynamics are calibrated in each region by imposing the assumption of a balanced growth path. This implies that the ratio between labor and capital (in efficiency units) is held constant over time.[9] When alternative scenarios around the baseline are simulated, the technical efficiency parameter is held constant, and the growth of capital is endogenously determined by the saving/investment relation.

[8] Swartz, Paul, and Tillman, Peter. "Foreign Ownership of U.S. Assets," Quarterly Update. Council on Foreign Relations. October 8, 2010.

[9] This involves computing in each period a measure of Harrod-neutral technical progress in the capital-labor bundle as a residual. This is a standard calibration procedure in dynamic CGE modeling.

1.10 Modelling Emissions

The BEAR model captures emissions from production activities in agriculture, industry, and services, as well as in final demand and use of final goods (e.g. appliances and autos). This is done by calibrating emission functions to each of these activities that vary depending upon the emission intensity of the inputs used for the activity in question. We model both CO2 and the other primary greenhouse gases, which are converted to CO2 equivalent. Following standards set in the research literature, emissions in production are modeled as factors inputs. The base version of the model does not have a full representation of emission reduction or abatement. Emissions abatement occurs by substituting additional labor or capital for emissions when an emissions tax is applied. This is an accepted modeling practice, although in specific instances it may either understate or overstate actual emissions reduction potential.[10] In this framework, emission levels have an underlying monotone relationship with production levels, but can be reduced by increasing use of other, productive factors such as capital and labor. The latter represent investments in lower intensity technologies, process cleaning activities, etc. An overall calibration procedure fits observed intensity levels to baseline activity and other factor/resource use levels. In some of the policy simulations we evaluate sectoral emission reduction scenarios, using specific cost and emission reduction factors, based on our earlier analysis.[11]

The BEAR model has the capacity to track 13 categories of individual pollutants and consolidated emission indexes, each of which is listed in Table A.1 below. Our focus in the current study is the emission of CO2 and other greenhouse gases, but the other effluents are of relevance to a variety of environmental policy issues. For more detail, please consult the full model documentation.

Table A.1. Emission Categories

Air Pollutants

Suspended Particles	PART
Sulfur Dioxide (SO_2)	SO2
Nitrogen Dioxide (NO_2)	NO2
Volatile organic compounds	VOC
Carbon monoxide (CO)	CO

[10] See e.g. Babiker et al (2001) "The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results" for details on a standard implementation of this approach.
[11] Hanemann, W. Michael, and Farrell, A.E. "Managing Greenhouse Gas Emissions in California." California Climate Change Center, University of California, Berkeley. January 2006. Available at: http://ee.hawaii.edu/~mfripp/papers/Hanemann_Farrell_2006_California_Climate.pdf

Toxic air index	TOXAIR
Biological air index	BIOAIR

Water Pollutants

Biochemical oxygen demand	BOD
Total suspended solids	TSS
Toxic water index	TOXWAT
Biological water index	BIOWAT

Land Pollutants

Toxic land index	TOXSOL
Biological land index	BIOSOL

Table A.2. Social Accounting Matrix for California, Structural Characteristics, 2016

- 103 production activities
- 103 commodities (includes trade and transport margins)
- 24 factors of production
- 22 labor categories
- Capital
- Land
- 9 Household types, defined by BLS income tax bracket
- Enterprises
- Federal Government (7 fiscal accounts)
- State Government (27 fiscal accounts)
- Local Government (11 fiscal accounts)
- Consolidated capital account
- External Trade Account

These data enable us to trace the effects of responses to climate change and other policies at unprecedented levels of detail, tracing linkages across the economy and clearly indicating the indirect benefits and tradeoffs that might result from comprehensive policies pollution taxes or trading systems. As we shall see in the results section, the effects of climate policy can be quite complex. In particular, cumulative indirect effects often outweigh direct consequences, and affected groups are often far from the policy target group. For these reasons, it is essential for policy makers to anticipate linkage effects like those revealed in a general equilibrium model and dataset like the ones used here.

It should be noted that the SAM used with BEAR departs in a few substantive respects from the original 2016 California SAM. The two main differences have to do with the structure of production, as reflected in the input-output accounts, and with consumption good aggregation. To specify production technology in the BEAR model, we rely on both activity and commodity accounting, while the original SAM has consolidated activity accounts. We chose to maintain separate activity and commodity accounts to maintain transparency in the technology of emissions and patterns of tax incidence. The difference is non-trivial and considerable additional effort was needed to reconcile use and make tables separately. This also facilitated the second SAM extension, however, where we maintained final demand at the full 119 commodity level of aggregation, rather than adopting six aggregate commodities like the original SAM.

1.11 Emissions Data

Emissions data were obtained from California's own detailed emissions inventory. In most of the primary pollution databases like this, measured emissions are directly associated with the volume of output. This has several consequences. First, from a behavioral perspective, the only way to reduce emissions, with a given technology, is to reduce output. This obviously biases results by exaggerating the abatement-growth tradeoff and sends a misleading and unwelcome message to policy makers.

More intrinsically, output based pollution modeling does not reflect the observed pattern of abatement behavior. Generally, firms respond to abatement incentives and penalties in much more complex and sophisticated ways by varying internal conditions of production. These responses include varying the sources, quality, and composition of inputs, choice of technology, etc. The third shortcoming of the output approach is that it gives us no guidance about other important pollution sources outside the production process, especially pollution in use of final goods. The most important example of this category is household consumption. The BEAR model estimates pollution in both production and consumption (e.g. fuel and energy use). In all cases, we calibrate to the California inventory for initial emission intensity, but going forward the model captures price sensitive fuel and technology substitution by enterprises and households. This is more consistent with observed reality.