GreenMod-SoCal

A Multi-Sector General Equilibrium Model for Southern California[1]

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1.0 INTRODUCTION

California has a long history of environmental activism and has frequently been a leader in setting environmental policy. The state continued this trend with the passage of the California Global Warming solutions Act of 2006 (AB32). AB32 requires the state to limit greenhouse gas emissions to 1990 levels by the year 2020. The legislation also authorizes the state Air Resources Board to adopt "market-based compliance mechanisms" that could be used to achieve the targeted level of emissions.

A major point of contention regarding regulation of greenhouse gases is the potential economic impact. Will this action by California reduce the state's competitiveness in the global markets? When the policy analyzed in a benefit-cost framework it becomes evident that the benefits will occur in the future and the costs will occur now. This dynamic distribution of the benefits and costs has become particularly problematic given the current economic climate. Any reduction in competitiveness now may result in a decrease in jobs and further negative impacts on the economy. Developing a model that helps to clarify the economic costs of the policy will be useful in informing the debate as to the appropriate targets and the costs to achieve these targets.

There have been a number of studies that have considered the state-wide impacts of meeting the greenhouse gas emissions target through various policy options. An example of the modelling effort is the Berkeley Energy and Resources model (BEAR) by Roland-Holst (2006). Roland-Holst finds that the policy will result in positive net benefits mainly as a result of the technological progress. This result is criticized by Stavins, Jaffe and Schatzki (2007). Stavins et al. believe that the costs are underestimated by Roland-Holst. Stavins et al. also critique two other state-wide studies that had come to similar conclusions.

The objective of this study is to estimate the policy results for controlling greenhouse gases for the southern California area. Specifically, we consider the policy impacts for the five county area that includes Los Angeles, Orange, Riverside, San Bernadino and Ventura. We construct a computable general equilibrium (CGE) model (GreenMod-SoCal) that aggregates the five country area into one region and then estimate the impact of an energy tax (price mechanism) policy.

The report is organized as follows. Section 2 provides the main technical features of the model, both the theoretical foundation and the empirical values used to solve the model. Section 3 presents the results of the policy counterfactual scenario for the energy tax. The final section provides a summary, conclusions and ideas for future research.

2.0 THE MODEL

GreenMod-SoCal is a static, multi-sector general equilibrium model for southern California. The model incorporates the economic behavior of four economic agents: firms, households, the government and the rest of the world. GreenMod-SoCal distinguishes 18 branches of activity, consisting of both public and private enterprises (see Table 1). Each branch of activity produces one or several types of goods and services, as reflected by the input-output[1] matrix. In total, there are 18 types of services and commodities, which follow the disaggregation presented in Table 2. Four of the commodities presented in Table 2 represent energy inputs: Oil and gas, electric power, refined petroleum and all other petroleum and coal products.

Table 1: Disaggregation of branches of activity in GreenMod-SoCal

[1] The input-output matrix was developed from IMPLAN.

1	Agriculture
2	Mining
3	Oil and Gas extraction
4	Water
5	Construction
6	Manufacturing
7	Petroleum refineries
8	All other petroleum and coal products manufacturing
9	Petrochemical manufacturing
10	Industrial gas manufacturing
11	Air transportation
12	Rail transportation
13	Water transportation
14	Truck transportation
15	Other transportation
16	Warehousing and storage
17	Retail
18	Miscellaneous

GreenMod-SoCal can be used for detailed impact and scenario analysis at the sectoral level. It helps its users understand the total macro and sectoral effects of policy decisions. It captures the inter-industry detail from input-output, supply and use tables. It allows for behavioral responses to changes in housing and consumer prices, wages, and production costs as in computable general equilibrium models. The model is static, and can be used to assess the role and particular contribution of sectors, commodity groups, households and various components of GDP when analysing a broad set of macro-economic variables, under the baseline situation as represented in the benchmark database as well as under policy scenarios. Besides, it captures the impact of economic activity, at the sectoral and aggregate level, on greenhouse gas emissions, and illustrates how the economic response of the agents in the model to policy adaptations can be used as determinant of changes in emission levels.

Table 2: Disaggregation of commodities in GreenMod-SoCal

1	Agricultural products
2	Oil and gas
3	Electric Power
4	Water
5	Construction
6	Manufacturing
7	Refined Petroleum
8	All other petroleum and coal products
9	Petrochemical manufacturing
10	Industrial gas manufacturing
11	Air transportation
12	Rail transportation
13	Water transportation
14	Truck transportation
15	Other transportation
16	Warehousing and storage
17	Retail
18	Miscellaneous

GreenMod-SoCal is based on general equilibrium theory. It is designed to measure the direct and indirect economic impacts of policy changes on the southern California economy in the short run. The input-output core enables the model to take particular relationships and dependencies into account between and among products, branches, institutions, and agents in the model when analyzing the impacts of shocks or trends, and consequently trace the extent and the channels of changes in policy or developments in the international environment. The resulting price changes affect the demand for the sectoral outputs and alter the resource allocation of production factors. Typically, simulations explore the effects of external shocks (such as changes in the international prices, the fluctuations in the real exchange rate, foreign demand, etc) and domestic policy changes. Model simulations provide results regarding the impacts on:

- GDP
- production by branch of activity
- value added by branch of activity
- trade flows by commodity
- employment
- investment
- macroeconomic variables (welfare measures, inflation, etc.)
- prices
- wages
- income
- public finance outcomes
- greenhouse gas emissions on fuel combustion
- etc.

This type of economic modelling is an important tool for analysing a great number of economic issues. Applied general equilibrium models are now widely used in economic policy analyzes by all the major international institutions such as the World Bank, the OECD, the European Commission, the World Trade Organisation, the UNCTAD, major multinational companies, hundreds of municipal administrations, and others. This widespread use is motivated by the capability of these models to provide an elaborate and realistic representation of the economy including the linkages between all agents, sectors and other economies. This complete coverage allows a unique insight into the effects of changes in the economic environment throughout the whole economy. These models are able to consider human capital accumulation, intergenerational issues, environmental issues, and health issues.

General equilibrium (CGE) models simulate the workings of a market economy and are unique in their ability to analyze the impacts of economic policy decisions, especially when the policy has macro and sectoral resource allocation repercussions. CGEs are explicitly designed to capture all structural impacts including changes in relative prices, demand composition, and sectoral output and employment.

The main premise of the CGE models is that "structure" matters and they explicitly consider the workings of a multi-sectoral, multi-market, general equilibrium system undergoing structural adjustment, i.e. CGE models simulate the transactions in a market economy. They capture the interaction of various actors in the economy including: households (as consumers, workers and savers); firms (as producers, consumers of intermediate goods, and investors); government (as consumer and transfer agent); and the rest of the world (as consumers of exports, producers of imports and providers or recipients of international capital flows). Consistent with microeconomic theory, all agents are assumed to optimize within budget constraints as well as the constraints imposed by regulatory frameworks. CGE models are unique in their ability to present the trade-offs of a given policy decision, especially when the policy has economy-wide repercussions as in the case of corporate, sales and individual income taxes or environmental taxes to correct for externalities. Even the sign of an affected variable may change when an analysis is extended from partial to general equilibrium.

One of the most desirable properties of CGE models is their ability to trace economy-wide implications of several policy changes *simultaneously*, taking into account both the interactions between these policy changes as well as the policy changes and existing distortions. The use of detailed inter-industry flow information allows the modelling of the interaction between industries that can result from the change in relative prices of specific commodities or the level of demand.

GreenMod-SoCal incorporates the economic behavior of four economic agents: firms, households, the government and the rest of the world. The behavior of each agent in the model will be described in detail. GreenMod-SoCal is currently calibrated on the Social Accounting Matrix for 2004 that will be described in detail below. The model has been solved by using the general algebraic modelling system GAMS (Rosenthal, 2006).

The following conventions are adopted for the presentation of the model. Variable names are given in capital letters, whereas small letters denote parameters calibrated from the database (SAM) and elasticity parameters. The subscript *s* denotes the production activities (consisting of 18 branches of activity), and the subscript *c* stands for commodities and services (18 types of commodities). The subscript *en* stands for the energy inputs used as intermediate consumption goods (4 types of energy inputs) while *nen* stands for all other commodities except the energy inputs (14 types of commodities). The subscript *enel* stands for the electricity and *ennel* for the non-electric energy inputs (3 types of energy inputs).

2.1 Firms

The CGE model does not take into account the behavior of individual firms, but of groups of similar ones aggregated into branches. The model distinguishes 18 branches of activity (summarized in Table 1).

When developing models in a CGE framework, it is typical to assume that producers operate in perfectly competitive markets and maximize profits (or, equivalently, minimize costs for each level of output) to determine optimal levels of inputs and output. For example, for the firms operating internationally, the world market dictates the output price to a large extent, and hence for an optimal outcome they have to produce as efficiently as possible. Some other firms are constrained in their cost level by domestic competitors. Thus, the optimizing producers minimize their production costs at every output level, given their production technology. Furthermore, production prices equal average and marginal costs, a condition that implies profit maximization for a constant returns-to-scale technology.

When determining the optimal combination of inputs in order to reach a certain output level, the firms are characterized by their production structure, describing the relation between inputs into the production process and the output resulting from their activity. For a quantitative analysis of these decisions, assumptions on the functional form and structure of the production functions that the firms face need to be made. In GreenMod-SoCal, two types of production function are combined in a nested hierarchical structure. On the one hand, a Leontief function defines fixed proportions of inputs that are required to yield a certain output. On the other hand, the Constant Elasticities of Substitution (CES) production function facilitates more flexibility, to the extent that it allows for substitution possibilities between inputs that are described by substitution *elasticities*. By combining the two functions in a structure consisting of multiple stages, the necessity to include certain (categories of) inputs in the production and the flexibility to combine or replace others can both be sensibly represented by the choice of a *nesting structure* reflecting these characteristics. Also, the importance of particular inputs in the production process of certain sectors can be incorporated by adapting the nesting scheme per sector.

Figure 1 illustrates the nested production structure that is assumed for all branches of activity in GreenMod-SoCal. This production structure, consisting of four nesting levels, is constituted by the combination of a Leontief function at the first level in the hierarchy, with several CES functions at lower nesting levels. The Leontief function defines how a bundle of capital, labor and energy is combined with non-energy commodities, which are used as intermediates, according to fixed coefficients, yielding final domestic production per sector. Next, the KLE bundle is split into labor and another bundle of Capital and Energy, according to a CES function, allowing for substitution between the two components expressed by the elasticity of substitution. In a similar fashion, the KE bundle is split into the production factor capital and a composite good including all energy inputs. Finally, this composite energy commodity is defined by its four constituents, allowing once again for substitution between the four types of commodities.

Once a nesting structure has been chosen for a particular branch of activity, and consequently the functional form has been set for every nesting level, one needs to assign values to the parameters defining these functions: for the Leontief production function, the fixed shares need to be determined and for the CES function the distribution and scale parameters and elasticities of substitution. Under the CGE methodology, most of these parameters are usually derived by *calibration* on a dataset (typically a Social Accounting Matrix) in the base year. In that way, parameters are calculated such that by definition the functional relationships defined by the nesting structure are satisfied. Whereas this provides very convenient solutions for parameters of a static nature, like Leontief shares or CES distribution parameters, the static dataset usually does not provide enough information for parameters of a more dynamic nature, such as elasticities of substitution. Therefore, these are typically determined by econometric studies on time series; in GreenMod-SoCal, various sources were consulted in order to find parameter values that are sensible to be used in the context of the California economy. These are described in greater detail below.

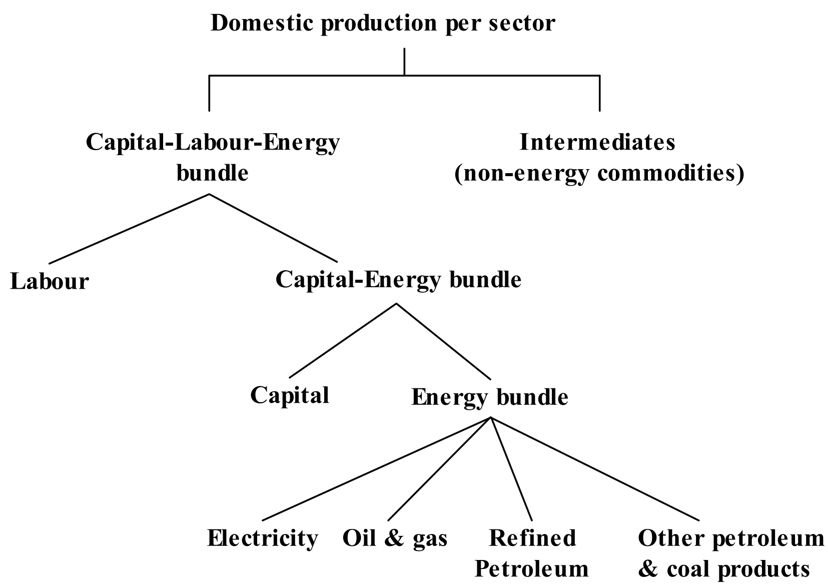

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Figure 1. The nested Leontief and CES production technology for domestic production at the sectoral level

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forms that were chosen. In particular, the assumptions that firms maximize profit on the one hand and that they operate in perfectly competitive markets on the other, lead to characteristic demand functions for the factors in the production function and to a zero profit condition, as outcomes of the (budget-)constrained (profit-)optimization process that describes the behavior of the producers in the economy. The shape of these functions is very similar throughout the model, and in the remainder of this section, they will be explicitly formulated for all the nests and branches in the production structure.

As is shown in figure 1, the domestic production by different sectors s is defined by a Leontief function with fixed proportions $aKLE_s$ defining the required input of the capital-labor-energy bundle (KLE_s) and, similarly, fixed technical coefficients $io_{c,s}$ defining the required quantities of total intermediate inputs $(IO_{c,s})$. Then, assuming an optimal allocation of inputs, the demand equations for the capital-labor-energy bundle and the intermediate inputs read:

$$KLE_s = aKLE_s \cdot XD_s \tag{1}$$

and

$$IO_s = \sum_c io_{c,s} \cdot XD_s \; . \tag{2}$$

Thus, domestic production valued at basic prices net of net production taxes, $\left[PD_s \cdot (1 - tp_s)\right]$, is given by the sum of the capital-labor-energy bundle (KLE_s) for branch s valued at sector-specific basic prices $(PKLE_s)$ and intermediate (non-energy) commodities used by sector s valued at the market price of the commodities (P_c), including taxes (tic_c) on intermediate consumption:

$$PD_s \cdot XD_s \cdot (1-tp_s) = \sum_{nen} \{ io_{nen,s} \cdot XD_s \cdot P_{nen} \cdot (1+tic_{nen}) \} + PKLE_s \cdot KLE_s \tag{3}$$

At the second level of the nesting structure, the capital-labor-energy bundle is assumed to be a CES aggregation of labor (L_s) and a bundle of capital and energy (KE_s), with a characteristic functional form:

$$KLE_s = aKLE_s \cdot (\gamma L_s \cdot L_s^{-\rho KLE_s} + \gamma KE_s \cdot KE_s^{-\rho KLE_s})^{-1/\rho KLE_s} , \tag{4}$$

where the distribution parameters γL_s and γKE_s sum up to one: $\gamma L_s + \gamma KE_s = 1$.

The corresponding cost function is the sum of the costs related to each input, valued at their price (wage) and price index, respectively:

$$Cost_s(L_s, KE_s) = PL \cdot (1+tl_s) \cdot L_s + PKE_s \cdot KE_s . \tag{5}$$

An implication of the adopted production structure in nests is that the demand for particular factors is determined hierarchically, i.e. as a function of the factor that is located right above them in the production structure. As a result, at every nest the producer is assumed to be a cost-minimizer, where the quantities of the underlying factors at the bottom of the nest are her instruments, under the constraint that the combination of these factors yields the required amount of the factor at the top of the nest, according to the production function in equation (4). The extent to which the production factors can be substituted at every nest is expressed by the elasticity of substitution. In equation (4), this substitution elasticity between labor and the capital-energy bundle is given by σKLE_s, where $\sigma KLE_s = 1/(1+\rho KLE_s)$.

Applying the cost-optimization as described above, minimization of the cost function (5) subject to the production function in equation (4) yields the characteristic CES demand equations for labor and the capital-energy bundle:

$$L_s = KLE_s \cdot (PKLE_s / [PL \cdot (1+tl_s)])^{\sigma KLE_s} \cdot \gamma L_s^{\sigma KLE_s} \cdot aKLE_s^{(\sigma KLE_s - 1)} \tag{6}$$

$$KE_s = KLE_s \cdot (PKLE_s / PKE_s)^{\sigma KLE_s} \cdot \gamma KE_s^{\sigma KLE_s} \cdot aKLE_s^{(\sigma KLE_s - 1)} \tag{7}$$

and the associated zero profit condition:

$$PKLE_s \cdot KLE_s = PL \cdot (1+tl_s) \cdot L_s + PKE_s \cdot KE_s \tag{8}$$

where PKE_s gives the price index corresponding to the capital-energy bundle, PL stands for the price of labor: the wage rate, and tl_s is the social security contributions rate for industry s.

At the third nest, the capital-energy bundle is a CES aggregation of capital (KSK_{sel}) and a composite energy commodity, $ENER_s$:

$$KE_s = aKE_s \cdot (\gamma K_s \cdot KSK_s^{-\rho KE_s} + \gamma ENER_s \cdot ENER_s^{-\rho KE_s})^{-1/\rho KE_s} \tag{9}$$

Similarly to the optimization procedure described above, minimizing the costs function:

$$Cost_s(KSK_s, ENER_s) = [PK_s \cdot (1+tk_s) + d_s \cdot PI_s] \cdot KSK_s + PENER_s \cdot ENER_s \tag{10}$$

subject to (9) yields the demand equations for capital and the energy composite:

$$KSK_s = KE_s \cdot \{ PKE_s / [PK_s \cdot (1+tk_s) + d_s \cdot PI_s] \}^{\sigma KE_s} \cdot \gamma K_s^{\sigma KE_s} \cdot aKE_s^{(\sigma KE_s - 1)} \tag{11}$$

$$ENER_s = KLE_s \cdot (PKLE_s / PENER_s)^{\sigma KE_s} \cdot \gamma ENER_s^{\sigma KE_s} \cdot aKE_s^{(\sigma KE_s - 1)} \qquad (12)$$

and the associated zero profit condition:

$$PKE_s \cdot KE_s = [PK_s \cdot (1 + tk_s) + d_s \cdot PI_s] \cdot KSK_s + PENER_s \cdot ENER_s \,, \qquad (13)$$

where PK_s is the return to capital in branch s, tk_s is the capital income tax rate for branch s, and d_s is the depreciation rate in industry s. The depreciation related to the (private and public) capital stock is valued at the price index corresponding to investments by branch of activity s (PI_s). The price index related to the energy bundle is denoted by $PENER_s$, and the elasticity of substitution between capital and the energy bundle is given by σKE_s, where $\sigma KE_s = 1/(1 + \rho KE_s)$, and γK_s and $\gamma ENER_s$ represent the distribution parameters corresponding to capital and the energy bundle.

Finally, at the fourth nest, the energy bundle is defined by a CES aggregation of its four constituents:

$$ENER_s = aENER_s \cdot \left(\sum_{en} \gamma ENINP_{en,s} \cdot ENINP_{en,s}^{-\rho ENINP_S}\right)^{-1/\rho ENINP_S} \,, \qquad (14)$$

with corresponding cost function

$$Cost_s(ENINP_{en,s}) = \sum_{en} \{ P_{en} \cdot (1 + tic_{en}) \cdot ENINP_{en,s} \} \,. \qquad (15)$$

Minimization of this function leads to the demand functions for each energy commodity:

$$ENINP_{en,s} = ENER_s \cdot \left\{ PENER_s / [P_{en} \cdot (1 + tic_{en})] \right\}^{\sigma ENER_s} \cdot \gamma ENINP_{en,s}^{\sigma ENER_s} \cdot aENER_s^{(\sigma ENER_s - 1)} \qquad (16)$$

and its associated zero profit condition:

$$PENER_s \cdot ENER_s = \sum_{en} \left\{ P_{en} \cdot (1 + tic_{en}) \cdot ENINP_{en,s} \right\} \,, \qquad (17)$$

where tic_{en} is the tax rate on intermediate consumption, and P_{en} the consumer price of the respective energy commodities.

As can be noted from equations above, capital is treated as being industry specific, allowing for rigidities in the capital market. On the other hand, the wage rate is constant over all sectors.

2.2 Households

The households in the southern California economy are modelled by one representative household, receiving the aggregated capital and labor income plus transfers from the other agents in the economy, minus the imputed social contributions. Government transfers comprise the social benefits other than social transfers in kind, property income and other current transfers. The household needs to pay personal income taxes over the gross income it receives, such that its net income can be derived by:

$$YHD = (1 - ty) \cdot YH \qquad (18)$$

Once the household has received its net income, it splits it between consumption and savings according to its marginal propensity to save. Hence, the household's savings (SH) are given by:

$$SH = MPS \cdot (1 - ty) \cdot YH \, , \tag{19}$$

where YH is the household income, ty is the personal income tax rate and MPS gives the household's propensity to save at the margin. The propensity to save reacts to changes in the after-tax average return to capital, according to:

$$MPS = MPSI \cdot \left(\frac{(1-ty) \cdot PKavr}{(1-tyz) \cdot PKavrZ} \right)^{elasS} \tag{20}$$

where $MPSI$ is the benchmark level of the propensity to save, $PKavr$ is the real average return to capital received by the household, $PKavrZ$ is the benchmark level of the real average return to capital received by the household, tyz is the benchmark level of the personal income tax rate and $elasS$ is the elasticity of the propensity to save to the return to capital. Subsequently, the household's budget disposable income for consumption $(CBUD)$ is derived as:

$$CBUD = (1-ty) \cdot YH - SH \tag{21}$$

The disposable income budget for consumption is allocated between different goods and services according to a Stone-Geary (Linear Expenditure System) utility function:

$$U(C_c) = \prod_c (C_c - \mu H_c)^{\alpha H_c} \, , \tag{22}$$

where U stands for utility, μH_c is the subsistence level of consumption that needs to be reached before any utility can be created, and αH_c is the parameter expressing the household's preferences. Hence, when allocating her disposable budget over the commodities in the economy, the consumer first decides on the minimum (subsistence) level of consumption of commodity c (μH_c). Then, the marginal income is allocated between different types of commodities according to the marginal budget shares (αH_c).

Maximization of this LES utility function subject to the budget constraint:

$$CBUD = \sum_c \{P_c \cdot (1+tc_c) \cdot C_c\} \tag{23}$$

yields the demand equations for commodities.

$$C_c = \mu H_c + \alpha HLES_c \cdot \left(\frac{CBUD - \sum_c P_c \cdot (1+tc_c) \cdot \mu H_c \}}{P_c \cdot (1+tc_c)} \right),$$

where, by definition, $\sum_c \alpha HLES_c = 1$.

Consumption of commodity c (C_c) is valued at purchaser's prices, which include the net taxes on consumption (tc_c), where P_c is the price of commodity c net of taxes.

A schematic representation of the household's decisions is given in figure 4.

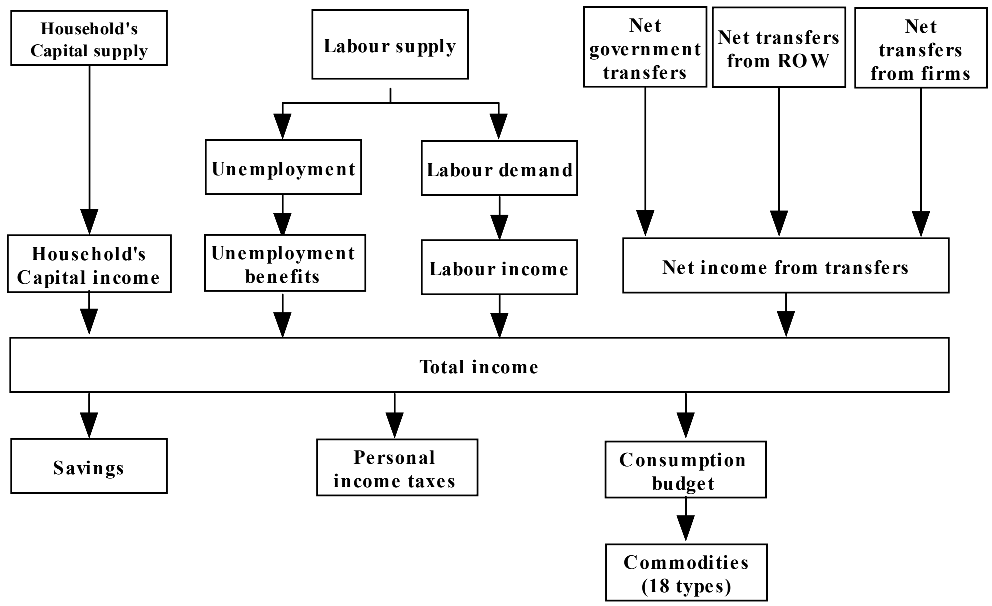

Figure 4. Decision structure of the household

When using the CGE model for an impact analysis of various types of scenarios, an issue that receives central attention is the household's welfare gain or loss. A method for quantifying changes in welfare is the equivalent variation in income (EV), which is based on the concept of a money metric indirect utility function (Varian, 1992).

$$EV = \prod_c \{[PZ_c \cdot (1+tcz)]/\alpha H_c\}^{\alpha H_c} \cdot (VU - VUI) \tag{24}$$

The indirect utility function (VU) corresponding to the Linear Expenditures System (LES) in the counterfactual (policy scenario) equilibrium is defined as:

$$VU = \left\{CBUD - \sum_c [P_c \cdot (1+tc_c) \cdot \mu H_c]\right\} \cdot \prod_c \{\alpha H_c / [P_c \cdot (1+tc_c)]\}^{\alpha H_c} \tag{25}$$

and the indirect utility function (VUI) in the benchmark equilibrium is analogously given by:

$$VUI = \left\{CBUDZ - \sum_c [PZ_c \cdot (1+tcz_c) \cdot \mu H_c]\right\} \cdot \prod_c \{\alpha H_c / [PZ_c \cdot (1+tcz_c)]\}^{\alpha H_c} \tag{26}$$

where $CBUDZ$ is the benchmark level of the disposable budget for consumption, PZ_c is the benchmark level of the price of commodity *c* net of taxes but including subsidies, and tcz_c are the benchmark rates corresponding to net taxes on consumption, respectively.

Equivalent variation measures the income needed to make the household as well off as it is in the new counterfactual equilibrium (policy scenario) evaluated at benchmark prices. Thus, the equivalent variation is positive for welfare gains from the policy scenario and negative for losses (Harrison and Kriström, 1997).

2.3 Government

The institutional unit 'Government' comprises all types of governments in the economy, from the local to the state level. As one of its main tasks, the representative government collects all the applicable taxes, such as: taxes on commodities, taxes on capital income, taxes on labor income, and taxes on production. In the derivation of each category of tax revenues a *fixed* tax rate is applied to the corresponding tax base that is *net* of subsidies. The taxes on commodities are split between the two categories of consumption that they apply to: intermediate consumption and final consumption.

Total government revenues are split into a part coming from tax claims, total tax revenues, and a part coming from other sources than levying taxes: the income from transfers. The first category consists of all the taxes mentioned above, and is split into three subcategories:

- Profit and personal income taxes:

$$TRPROP = ty \cdot YH + \sum_s (tk_s \cdot KSK_s \cdot PK_s) \ ,$$

where ty is the personal income tax and tk_s the tax rate on profits per sector.

- Social security contributions:

$$TRSOCT = \sum_s (tl_s \cdot LSK_s \cdot PL) \ ,$$

where tl_{sec} is the tax rate on labor use.

- Taxes on products

$$\begin{aligned} TRPROD = \ & \sum_s \sum_{en} \left\{ ENINP_{(en,s)} \cdot P_{en} \cdot tic_{en}) \right\} + \sum_s \sum_{nen} \left\{ io_{(nen,sec)} \cdot XD_s \cdot P_{nen} \cdot tic_{nen}) \right\} + \\ & \sum_c \left\{ P_c \cdot tc_c \cdot C_c + P_c \cdot ti_c \cdot I_c \right\} \end{aligned}$$

In the latter equation, the first line corresponds to taxes on intermediate consumption, regarding energy commodities and all other commodities, subsequently. The second line refers to taxes on final consumption and taxes on investment commodities.

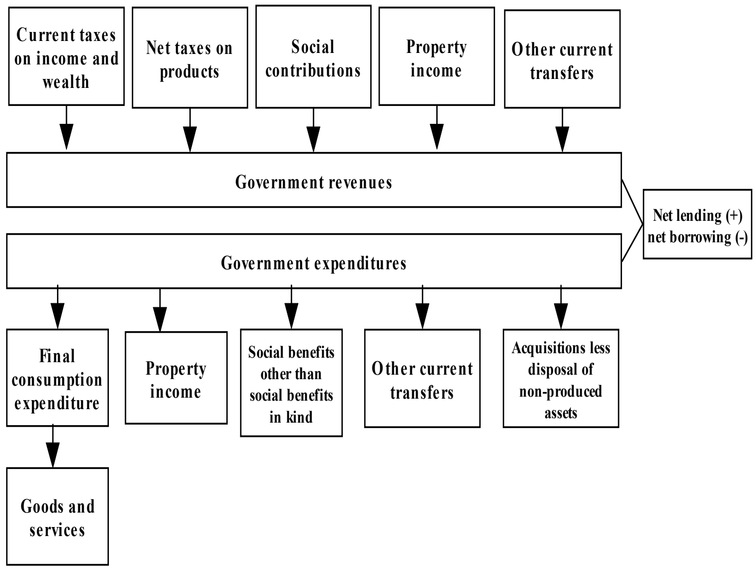

Figure 5. Structure of the government budget

In addition to tax revenues, the government receives income from transfers:

$$TRANSR = TRGW \cdot ER + TRGF \cdot GDPdef + TRGG \cdot GDPdef \ , \tag{27}$$

where *TRGW* are the transfers received by the government from the rest of the world, *TRGF* are the transfers received from the firms and *TRGG* are the transfers from the government to itself. The transfers include several categories of transfers, such as: current taxes on income and wealth, other transfers etc. Property income is included under this header and is treated as an exogenous variable in the model. Consequently, it is assumed to follow the price path of the price index.

Total government expenditures $(GEXP)$ comprise government final consumption expenditure $(CGBUD)$, and transfers to the other agents in the economy:

$$GEXP = CGBUD + TRANS \ . \tag{28}$$

Government final consumption expenditure by commodity (CG_c) is related to total final consumption expenditure through a Cobb-Douglas utility function:

$$P_c \cdot CG_c = \alpha CG_c \cdot CGBUD \ , \tag{29}$$

where αCG_c is the share of consumption of commodity c in the total final consumption expenditure by the government.

The transfers are composed of three parts:

$$TRANS = TRHG + TRFG \cdot GDPdef + TRGG \cdot GDPdef \ , \tag{30}$$

where the transfers to the firms (*TRFG*) and to the government itself (*TRGG*) are treated as exogenous. The transfers from the government to the households are determined endogenously and are composed of two parts: social benefits (other than social benefits in kind) and other current transfers. Social benefits other than social transfers in kind consist of unemployment benefits, determined by the combination of the replacement rate $(trep)$, the wage, the number of unemployed $(UNEMP)$ and the share of this group that actually receives unemployment benefits:

$$UNEMPB = trep \cdot PL \cdot UNEMP \cdot shUNEMPB\ . \tag{31}$$

The other current transfers received by the household from the government in real terms $(TRHGOTH)$ are fixed and are expressed in nominal terms using the consumer price index $(PCINDEX)$, such that total transfers from government to the household are determined by:

$$TRHG = UNEMPB + TRGOTH \cdot PCINDEX\ . \tag{32}$$

In addition, property income payable, capital transfers payable and acquisitions less disposal of non-produced assets are regarded as government expenditures. However, these expenditures are not explicitly modelled in GreenMod-SoCal but rather implicitly included in the revenue equation, where their respective counterparts (i.e. property income receivable, capital transfers receivable, etc.) are net values.

The difference between government revenues and government expenditures gives the government net lending (+)/net borrowing (-) in nominal terms (SG):

$$SG = GREV - GEXP\ . \tag{33}$$

2.4 Foreign trade

The specification of foreign trade is based on the small-country assumption, which means that the region under consideration is a price taker in both its import and its export markets.

On the import side, imperfect substitution is assumed between domestically produced and imported goods, according to the Armington function (see Figure 6). Thus, domestic consumers use composite goods (X_c) of imported and domestically produced goods, according to a CES function:

$$X_c = aA_c \cdot (\gamma A1_c \cdot (\sum_s XDD_{c,s})^{-\rho A_c} + \gamma A2_c \cdot M_c^{-\rho A_c})^{-1/\rho A_c} \tag{34}$$

Minimizing the cost function:

$$Cost_c(XDD_c, M_c) = \sum_s PDD_{s,c} \cdot XDD_{s,c} + PM_c \cdot M_c \tag{35}$$

subject to (34) provides the demand for imports (M_c) and demand for domestically produced goods $(XDD_{s,c})$:

$$M_c = X_c \cdot (P_c/PM_c)^{\sigma A_c} \cdot \gamma A2_c^{\sigma A_c} \cdot aA_c^{(\sigma A_c - 1)} \tag{36}$$

$$XDD_{s,c} = X_c \cdot (P_c/PDD_{s,c})^{\sigma A_c} \cdot \gamma A1_c^{\sigma A_c} \cdot aA_c^{(\sigma A_c - 1)} \tag{37}$$

and the corresponding zero profit condition related to the Armington assumption:

$$P_c \cdot X_c = PM_c \cdot M_c + \sum_s PDD_c \cdot XDD_c\ , \tag{38}$$

where P_c is the price index of the composite good *c* incorporating the imported and domestically produced goods supplied on the domestic market, PM_c represents the domestic price of imports and PDD_c is the price of good c. aA_c represents the efficiency parameter while $\gamma A1_c$ and $\gamma A2_c$ are the distribution parameters corresponding to domestic demand for the domestically produced goods and the demand for imports, respectively. The elasticity of substitution between imports and domestically produced goods (σA_c) is given by $1/(1+\rho A_c)$.

In a similar fashion, the differentiation by the domestic producers between the exported goods (E_s) and the domestic goods supplied on the domestic market $(XDD_{s,c})$ is captured through a constant elasticity of transformation (CET) function:

$$XD_s = aT_s \cdot (\gamma T1_s \cdot [\sum_c XDD_{s,c}]^{-\rho T_s} + \gamma T2_s \cdot E_s^{-\rho T_s})^{-1/\rho T_s} \tag{39}$$

where XD_s is the domestic production of sector s, supplied in the home and foreign markets, aT_s is the efficiency parameter, $\gamma T1_s$ and $\gamma T2_s$ are the distribution parameters corresponding to XDD_s and E_s, respectively, and the elasticity of transformation (σT_s) between domestically produced goods supplied on the domestic market and the exports by the domestic producers is given by $1/(1+\rho T_s)$.

By maximizing revenue:

$$Revenue_c(XDD_c, E_c) = \sum_s PDD_{s,c} \cdot XDD_{s,c} + PE_c \cdot E_c \tag{40}$$

subject to (39) we derive the supply of exports by the domestic producers and the supply by the domestic producers to the domestic market:

$$E_s = XD_s \cdot (PD_s/PE_s)^{\sigma T_s} \cdot \gamma T2_s^{\sigma T_s} \cdot aT_s^{(\sigma T_s - 1)} \tag{41}$$

$$XDD_{s,c} = XD_s \cdot (PD_s/PDD_{s,c})^{\sigma T_s} \cdot \gamma T1_s^{\sigma T_s} \cdot aT_s^{(\sigma T_s - 1)} \tag{42}$$

and the corresponding zero profit condition:

$$PD_s \cdot XD_s = \sum_c PDD_{s,c} \cdot XDD_{s,c} + PE_s \cdot E_s \tag{43}$$

where PD_s is the price corresponding to XD_s, and PE_s represents the domestic price of exports received by the domestic producers.

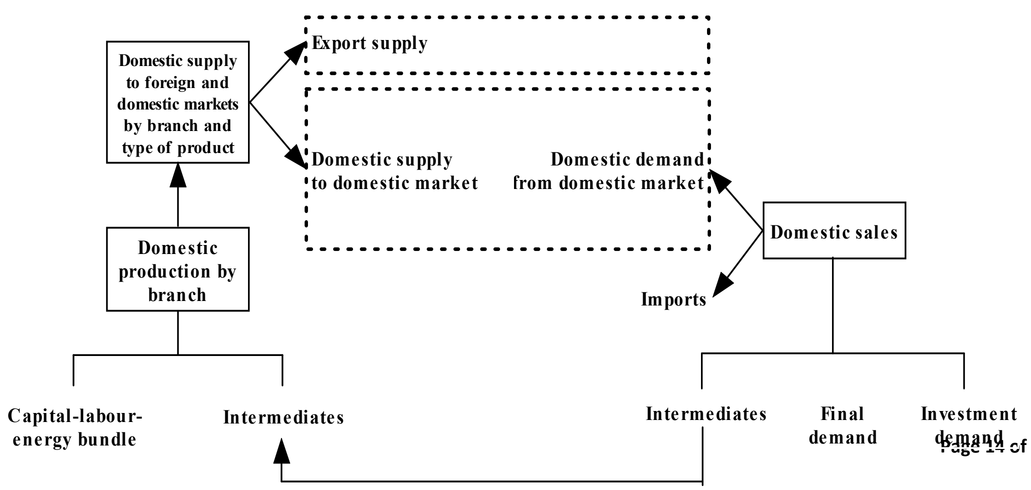

Figure 6. Foreign trade specification

The balance of payments takes into account all the trade and capital flows:

$$\sum_c M_c \cdot PWM_c + TRWF + TRWH + TRWG = \sum_s (E_s \cdot PE_s) + SW \quad (44)$$

where PWM_c is the world price of imports of commodity *c*, $TRWF$,$TRWH$ and $TRWG$ are the net transfers received by the rest of the world from the firms, household and government, respectively, and $SROW$ reflects the surplus/deficit of the current account.

2.5 Investment demand

Total savings (S) used to buy investment goods are given by:

$$S = SH + SF + SG + SW \cdot ER + \sum_s \left(d_s \cdot KSK_s \cdot PI\right) \quad (45)$$

where SH represents the household savings, SG is the government net lending (-)/ net borrowing (+) in nominal terms, SW is the current account balance expressed in the domestic currency using the exchange rate (ER), SF are the savings made by the firms and $\sum_s d_s \cdot KSK_s \cdot PI$ is the depreciation valued at the price index of investments (PI), where d_s is the depreciation rate and KSK_s gives the capital stock of industry *s*.

Total investments in real terms (ITT) are given by:

$$PI \cdot ITT = (S - \sum_c SV_c \cdot P_c) \quad (46)$$

where SV_c stands for the change in inventories of commodity *c*, that is determined as a fixed share of total supply of commodity *c*:

$$SV_c = svr_c \cdot X_c \quad (47)$$

The optimal allocation of total investments (ITT) between different types of investment commodities (I_c) is given by a Leontief function:

$$I_c = ioI_c \cdot ITT \quad (48)$$

where ioI_c is a parameter that provides the composition of total investments in terms of investment goods.

The composite price (unit cost) of investments (PI) is defined as the weighted average of the price of investment goods:

$$PI = \sum_c \{(1+ti_c) \cdot P_c \cdot ioI_c\} \quad (49)$$

where P_c stands for the price of (investment) commodity *c* and ti_c is the tax rate on investment good *c*.

2.6 Price equations

A common assumption for CGE models, which has also been adopted here, is that the economy is initially in equilibrium with the quantities normalized in such a way that prices of commodities equal unity. Due to the homogeneity of degree zero in prices, the model only determines relative prices. Therefore, a particular price is selected to provide the numeraire price level against which all other prices in the model will be measured in relative terms. In this case, the GDP deflator $(GDPDEF)$ is chosen as the numeraire, which is defined as the ratio of GDP at current market prices to GDP at constant prices. GDP is the aggregate value for the five county region (SoCal).

Different prices are defined for all the branches, exports and imports. The domestic price of exports (PE_s) reflects the price received by the domestic producers for selling their production on the foreign market. The domestic price of net exports received by the domestic producers is given by the world price of exports and expressed in dollars by the exchange rate:

$$PE_s = PWE_s \cdot ER\,. \tag{50}$$

The domestic price of imports (PM_c) is determined by the world price of imports and the exchange rate:

$$PM_c = PWM_c \cdot ER \tag{51}$$

The consumer price index $(PCINDEX)$ used in the model is of the Laspeyres type and is defined as:

$$PCINDEX = \frac{\sum_c \{ P_c \cdot (1+tc_c) \cdot CZ_c \}}{\sum_c \{ PZ_c \cdot (1+tcz_c) \cdot CZ_c \}} \tag{52}$$

where P_c is the price index of commodity *c* net of taxes but including subsidies and PZ_c gives its benchmark level, tc_c gives the tax rate corresponding to other taxes on products, with tcz_c as benchmark levels. Finally, CZ_c accounts for the benchmark level of private consumption of commodity *c*.

Consumer prices (PCT_c) are further defined as:

$$PCT_c = P_c \cdot (1+tc_c)\,. \tag{53}$$

Finally, the average return to capital comes from:

$$PKavr = \sum_s \left(PK_s \,/\, PCINDEX \cdot KSK_s \right) / \sum_s KSK_s\,. \tag{54}$$

2.7 Labor market

The following identity defines the relation between the labor supply, the labor demand, and unemployment:

$$\sum_s L_s = LSR - UNEMP \tag{55}$$

where L_s is the number of employees in industry *s*, $UNEMP$ represents the number of unemployed and LSR reflects the active population.

The responsiveness of the real wage to changes in labor market conditions is expressed by a wage curve:

$$log\left(\frac{PL}{PCINDEX}\right) = elas_U \cdot log(UNRATE) + \varepsilon \tag{56}$$

where PL is the nominal wage corresponding to regional wages, $PCINDEX$ is the consumer price index, $UNRATE$ provides the unemployment rate, ε is the error term and the unemployment elasticity $(elas_U)$ has been set to -0.1 (Sanz-de-Galdeano and Turunen, 2006).

Labor supply is provided by the equation:

$$LSR = LSRI \cdot \left(\frac{PL \cdot (1\text{-}ty) \cdot PCINDEXZ}{PLZ \cdot (1\text{-}tyz) \cdot PCINDEX}\right)^{elasLS} \tag{57}$$

where $LSRI$ is the benchmark level corresponding to the active population, ty is the personal income tax rate, and $PLAVRZ$, $PCINDEXZ$, tyz are the benchmark levels corresponding to the nominal wage, CPI and personal income tax rate, respectively. The real wage elasticity of the labor supply $(elasLS)$ has been set to 0.2.

Regional employment is given by:

$$EMPN = LSR - UNEMP \tag{58}$$

2.8 Market clearing equations

When formulating a CGE model and searching for its equilibrium, it is important to identify two types of variables: nominal and real. Real variables express quantities of commodities or units of capital or labor, whereas, nominal are typically expressed in terms of their relative level or value compared to the price of one chosen reference in the model: a numeraire. In this way, the search for a general equilibrium comes down to the search for a combination of prices that simultaneously clear all markets, and all these prices will be expressed in relative terms to the numeraire. When selecting prices as the instrument for finding a general equilibrium in the model, the formulation of the optimization problem aimed at finding this price system needs to include constraints that define the equilibrium that one is looking for: the market clearing conditions.

The existence of equilibrium in the labor market requires that demand equals supply at prevailing wages, taking into account unemployment. The corresponding labor market clearing equation has already been presented above. Regarding the capital market, the capital stock is sector specific, such that the required equality between capital demand and supply determines the return to capital by branch of activity.

Separate market clearing equations are distinguished in the model for each commodity *c*. Similarly to the division of commodities that was made considering the production structure of the firms, a distinction is made here between energy commodities and all other commodities, facing different definitions regarding their total demand. The market clearing equations corresponding to all commodities except the energy inputs (*nen*) are given by:

$$X_{nen} = C_{nen} + CG_{nen} + I_{nen} + SV_{nen} + \sum_{s} io_{nen,s} \cdot XD_s \ , \tag{59}$$

The left hand side defines total supply to the domestic market, whereas the right hand side expresses the different components of demand: final private consumption, public consumption investment demand, change in inventories and intermediate consumption.

For the energy inputs the sum of demand for energy input *en* $(\sum_{s} ENINP_{en,s})$, the private demand for energy input *en* (C_{en}), the public demand for energy input *en* (CG_{en}) and the change in inventories (SV_{en}) should be equal to the total supply of commodity *en* (X_{en}) from imports and domestic production:

$$X_{en} = C_{en} + CG_{en} + I_{en} + SV_{en} + \sum_{s} ENINP_{eng,s} \tag{60}$$

In both equations, the demand for inventories for each commodity *c* is defined as a fixed share of its domestic sales:

$$SV_c = svr_c \cdot X_c \tag{61}$$

In the current version of the model, trade and transport margins are not explicitly modelled.

2.9 Other macroeconomic indicators

Gross domestic product is provided at both constant prices (GDP) and at current market prices $(GDPC)$:

$$\begin{aligned} GDP = \ & \sum_{c} \{ C_c \cdot PZ_c \cdot (1+tcz_c) + CG_c \times PZ_c + I_c \cdot (1+tiz_c) \cdot PZ_c + \\ & SV_c \cdot PZ_c - M_c \cdot PWMZ_c \cdot ERZ \} + \sum_{s} \{ E_s \cdot PWEZ_s \cdot ERZ \} \end{aligned} \tag{62}$$

$$\begin{aligned} GDPC = \ & \sum_{c} \{ C_c \cdot P_c \cdot (1+tc_c) + CG_c \cdot P_c + I_c \cdot (1+ti_c) \cdot P_c + \\ & SV_c \cdot P_c - M_c \cdot PWM_c \cdot ER \} + \sum_{s} E_s \cdot PWE_s \cdot ER \end{aligned} \tag{63}$$

where $PWMZ_c$, PWE_s and ERZ represent the benchmark levels corresponding to the world price of imports, domestic price of exports f.o.b. and the real exchange rate, respectively.

2.10 GHG emissions

GreenMod-SoCal explicitly takes into account the evolution of the CO2 emissions on fuel combustion, by linking them to the consumption of energy. This link is created in two steps, due to differences in the units of measurement of energy consumption: in the model (and the underlying SAM), consumption is measured in monetary units, whereas the required units to derive emissions are units of energy (Kilo tons of oil equivalent, Ktoe). In order to appropriately derive GHG emissions from economic activity, one therefore first needs to determine the physical consumption in Ktoe and next link a certain amount of emissions, typically measured in Kt per Ktoe, per type of energy commodity and per branch of activity. In GreenMod-SoCal, a distinction is made between emissions stemming from intermediate consumption, which entails the demand for energy commodities by firms as part of their production process, and final consumption of energy commodities by the households.

The Social Accounting Matrix for southern California provides the consumption of energy in economic value terms (dollars). In order to be able to link these economic values to figures on energy consumption in physical terms, a scaling factor is applied to the values in the SAM that can be interpreted as an implicit price level for the energy vector (expressed in $/Ktoe). These scaling factors have been calculated by branch of activity using the SAM and the energy balance for the base year 2004. Using the implicit prices, physical consumption in energy units can be derived from results on consumption in economic terms that are obtained from the CGE model. Similarly, the implicit price levels for the energy vector (expressed in $/Ktoe) consumed by the residential sector have been derived using the SAM and the energy balance.

Next, CO2 emissions on fuel combustion by branch of activity, expressed in Kt, are derived from the total consumption of energy in physical terms by applying a CO2 emission factor to the amount of energy consumption, defining the emissions per unit of energy. As a result, the equation that determines the CO2 emissions per sector reads:

$$CO2EMIS_s = CO2Factor \cdot \sum_{ennel} \left(ENINP_{ennel,s} \cdot scalfactor1_{ennel} \right) \quad , \tag{64}$$

where *scalfactor1* is the scaling factor providing energy consumption in physical terms from the economic figures given by $ENINP_{ennel,s}$, and *CO2Factor* is the factor bridging consumption of energy commodities with a emission level.

For the residential sector, the equation is analogous:

$$CO2EMISP = CO2Factor \cdot \sum_{ennel} \left(C_{ennel} \cdot scalfactor2_{ennel} + CG_{ennel} \cdot scalfactor3_{ennel} \right) . \tag{65}$$

Finally, the total CO2 emissions in southern California are defined as the sum of the two:

$$CO2EMIST = \sum_{s} CO2EMIS_s + CO2EMISP \; . \tag{66}$$

2.11 Closure rules

The closure rules refer to the manner in which demand and supply of commodities, the macroeconomic identities and the factor markets are equilibrated ex-post. Due to the complexity of the model, a combination of closure rules is needed. The particular set of closure rules should also be consistent, to the largest extent possible, with the institutional structure of the economy and with the purpose of the model.

In mathematical terms, the model should consist of an equal number of independent equations and endogenous variables. The closure rules reflect the choice of the model builder of which variables are exogenous and which variables are endogenous, so as to achieve ex-post equality. Three macro balances are usually identified in CGE models that can be a potential source of ex-ante disequilibria and must be reconciled ex-post (Adelman and Robinson, 1989):

- The savings-investment balance;

- The government balance;
- The external balance.

The most widely accepted macro closure rule for CGE models implies the assumption that investment and savings balance. In the model, the investment is assumed to adjust to the available domestic and foreign savings. This reflects an economy in which savings forms a binding constraint. The interest rate is assumed to effectively balance the supply and demand for investments, even if the specific mechanism is not incorporated in the model.

Additional assumptions are needed with regard to government behavior in GreenMod-SoCal. First, the share of final consumptive expenditures by the government in GDP is fixed in real terms while the allocation of total expenditures over the consumption of different goods and services is provided by a Cobb-Douglas function. Second, the share of other transfers flowing from the government to the households, besides unemployment benefits, it similarly fixed with regards to the real GDP. Thus, the government net lending (+)/ net borrowing (-) is endogenously determined in the current version of GreenMod-SoCal. Alternative assumptions are possible, where total government expenditures can be fixed in real terms or as a share of GDP, while the total final expenditures adjust.

With respect to the external balance, the current account balance, expressed as a fraction of GDP, is exogenously fixed in the present version of GreenMod-SoCal, whereas the real exchange rate is determined endogenously.

The setup of the closure rules is important in determining the mechanisms governing the model. Therefore, the closure rules should be established also taking into account the policy scenario in question.

According to Walras' law if *(n-1)* markets are cleared the *n*th one is cleared as well. Therefore, in order to avoid over-determination of the model, the equation for labor market clearing has been dropped (see equation (55), section 2.7). However, the system of equations guarantees, through Walras' law, that domestic employment is equal to the active population plus the number of commuters less the number of unemployed.

2.12 Values for GreenMod-SoCal parameters

A CGE model can be written as a system of equations containing a set of unknown parameters θ, such that a vector of exogenous variables, X, produces a vector of endogenous variables Y (Adams and Higgs, 1990):

$$F(Y, X, \theta, \varepsilon) = 0$$

where ε is a vector of stochastic disturbances of either known, partially known or unknown distribution.

The calibration approach implies that:

$$\varepsilon = 0$$

Therefore, the resulting system of equations can be solved for the vector of parameters θ, using only one observation for the base year. The base year data represent the benchmark equilibrium data set or, more specifically, the Social Accounting Matrix. Parameters whose values cannot be inferred from the benchmark equilibrium data set (such as elasticities of substitution in most cases) are econometrically estimated, determined through expert knowledge (or obtained by a combination of the two), or obtained from the literature.

The restriction $\varepsilon = 0$ implies that calibration can be interpreted as a non-stochastic approach, as opposed to the stochastic approach of econometrics. This does not mean that economic reality is seen as deterministic when calibrating the CGE models. However, CGE models analyze the systematic, not the random, responses of economic variables to exogenous stimuli. Thus, ideally, the set of parameters θ of the CGE model produces the systematic part of the total response in Y, with a given X.

A number of parameters in GreenMod-SoCal are based on a literature survey the:

- elasticity of substitution between capital and labor;
- elasticity of substitution between imports and domestic goods;
- elasticity of substitution between exports and domestic goods;
- income elasticity of demand for consumption goods;
- elasticity of real wages to the unemployment rate; and
- real wage elasticity of labor supply.

There is little agreement on the magnitude of the substitutability between capital and labor in production. Most existing studies focus on the US economy. The use of capital stock data has generally produced estimates ranging between zero and unity (Arrow, Chenery, Minhas and Solow, 1961; Harrison, Jones, Kimbell and Wigle, 1993; Berndt, 1991; Jorgenson and Yun, 2001). Chirinko, Fazzary and Meyer (2004) estimate an elasticity of approximately 0.40, while Klump, McAdam and Willman (2007) also find that the elasticity of substitution is significantly below unity (between 0.5 and 0.6). Using a new data set from the Bureau of Economic Analysis, Balistreri, McDaniel and Wong (2003) estimate substitution elasticities for 28 industries that cover the entire US economy. Their range of point estimates is between 0.307 and 3.736, higher than the range of existing estimates: 0.16–1.33 (Eisner and Nadiri, 1968).

Kemfert and Welsch (2000) consider two different data sets for the German industry: an aggregate time series data for the entire German industry for the period 1970-1988 and a disaggregated time series data for the period 1970-1988 for seven industrial sectors: chemical products, stone and earth, iron, nonferrous metal, transport, food and paper. Their estimate for the whole industry is approximately 0.79, while the estimates by branch are low for the transport (0.17) and nonferrous metal (0.20) industries and in the range of 0.52-0.58 for the other five industries. The choice of the elasticity values in GreenMod-SoCal are presented in Table 3. These values are consistent with the literature survey.

CGE models typically derive elasticities of substitution between domestic goods and imports from econometric work that uses time series variation in prices (Alaouze et al., 1977; Stern et al., 1976; Gallaway et al., 2003). These estimates take the price variation as exogenous in estimating the import demand functions, ignoring the quality variation, and therefore tend to systematically understate the true elasticity (Hertel, Hummels, Ivanic and Keeney, 2007).

Table 3: Values of the elasticities of substitution in GreenMod-SoCal

	sigmaKLE	*sigmaKE*	*sigmaENER*	σT
Agriculture	1.20	0.25	0.10	-2.0
Mining	1.20	0.25	0.10	-2.0
Oil and Gas extraction	1.20	0.25	0.10	-2.0
Water	1.20	0.25	0.10	-2.0
Construction	1.20	0.25	0.10	-2.0
Manufacturing	1.20	0.25	0.10	-2.0

Petroleum refineries	1.20	0.25	0.10	-2.0
All other petroleum and coal products manufacturing	1.20	0.25	0.10	-2.0
Petrochemical manufacturing	1.20	0.25	0.10	-2.0
Industrial gas manufacturing	1.20	0.25	0.10	-2.0
Air transportation	1.20	0.25	0.10	-2.0
Rail transportation	1.20	0.25	0.10	-2.0
Water transportation	1.20	0.25	0.10	-2.0
Truck transportation	1.20	0.25	0.10	-2.0
Other transportation	1.20	0.25	0.10	-2.0
Warehousing and storage	1.20	0.25	0.10	-2.0
Retail	1.20	0.25	0.10	-2.0
Miscellaneous	1.20	0.25	0.10	-2.0

Note: σKLEN stands for the elasticity of substitution between value added and the energy bundle; σF stands for the elasticity of substitution between capital and labor; σENER stands for the elasticity of substitution between electricity and the non-electric energy bundle; σENINP stands for the elasticity of substitution between non-electric energy inputs; σENERCO stands for the elasticity of substitution between the coal-oil bundle and natural gas in the production function of the electricity sector.

In more recent work, Hertel, Hummels, Ivanic and Keeney (2007) employ a cross-section data set, built by Hummels (1999), drawing on tariffs and bilateral transportation costs for goods traded internationally. The reason for taking into account transportation costs is that in cross-section studies they vary more widely than tariffs do, allowing more accurate estimation for the trade elasticities. Compared to the previous estimates, the average of the estimates at 40 industry level is 7.0, larger than the average corresponding to previous estimates (around 5.3). Even though the difference between the two average estimates is rather small, there is much greater variation in the econometrically estimated elasticities by industry. The elasticities of substitution between imports and domestic goods in GreenMod-SoCal draw on Hertel, Hummels, Ivanic and Keeney (2007).

Table 4: Values of the elasticities of substitution and income elasticity of demand in GreenMod-SoCal

	elasY	σA
Agriculture	1.31	3.50
Mining	1.31	3.50
Oil and Gas extraction	1.31	3.50
Water	1.31	3.50
Construction	1.31	3.50
Manufacturing	1.31	3.50
Petroleum refineries	1.31	3.50
All other petroleum and coal products manufacturing	1.31	3.50
Petrochemical manufacturing	1.31	3.50
Industrial gas manufacturing	1.31	3.50
Air transportation	1.31	3.50
Rail transportation	1.31	3.50
Water transportation	1.31	3.50
Truck transportation	1.31	3.50
Other transportation	1.31	3.50
Warehousing and storage	1.31	3.50

Retail	1.31	3.50
Miscellaneous	1.31	3.50

Note: σA stands for the elasticity of substitution between composite imports and domestic goods; σT stands for the elasticity of substitution between composite exports and domestic goods; elasY stands for the income elasticity of demand for consumption goods; elasE stands for the price elasticity of export demand.

The elasticity of substitution between exports and domestic goods and the price elasticity of export demand in GreenMod-SoCal are consistent with the degree of openness of the economy and in line with the values used by Burniaux et al. (1992) and Weyerbrock (1998) for the EU (Table 4).

The income elasticities of demand for consumption goods (Table 4) rely on estimates by Seale, Regmi and Bernstein (2003). They use a two-stage, cross-country demand system fit to the 1996 International Comparison Project (ICP) data to estimate income elasticities for nine broad categories of consumption across 114 countries. The consumption groups include: food, beverage and tobacco; clothing and footwear; education; gross rent, fuel and power; house furnishings and operations; medical care; recreation; transport and communications; and other items.

The elasticity of real wages with respect to the unemployment rate in GreenMod-SoCal draws on the estimate by Sanz-de-Galdeano and Turunen (2006) for the euro area (Table 5). They use longitudinal micro data to examine the wage curve for the euro area over the period 1994-2001.

Table 5: Values of other parameters in GreenMod-SoCal

	Value
Frisch parameter	-1.10
ElasU	-0.13
ElasLS	0.20
ElasS	0.40

The wage elasticity of labor supply plays an important role, especially in evaluating the magnitude of the efficiency cost of income taxation. A large number of studies have estimated the uncompensated elasticity of labor supply. However, the variation in the results and the methodologies to estimate the elasticity is large: see Blundell and MaCurdy (1999) for an extensive review. Two robust findings about the elasticity can be drawn from the literature: first, the real wage elasticity of labor supply of women exceeds that of men and secondly, the elasticity regarding the decision to participate (the extensive margin) is larger than the elasticity of the decision regarding the hours worked (the intensive margin). Evers, Mooij and van Vuuren (2005) construct a "meta sample" using empirical estimates of the elasticity found in the literature with the aim to identify the sources of variation in empirical estimates of the uncompensated labor supply elasticity. The variation in elasticity values are explained by study characteristics, running meta regressions. Using a sample of 239 elasticities drawn from 32 empirical studies in the literature they conclude that the assumption regarding the relation between the hours worked and the wage rate (linear, quadratic, log-linear or double-log) does not have a significant impact on the elasticity estimates; the difference between elasticities among countries is small; and females have a larger labor supply elasticity than males, even after controlling for participation rates. Drawing on their analysis, the wage elasticity of labor supply (for both women and men) used in GreenMod-SoCal is provided in Table 5. Other studies (Immervoll et al., 2005) employ even lower values which correspond to wage elasticity of labor supply for Russia (around 0.1).

The range of empirical results corresponding to the effects of the net-of-tax rates of return on savings is also wide. From a theoretical point of view, an increase in the rate of return generates both an income and a substitution effect which go in opposite directions. Elmendorf (1996) underlines an additional “wealth” effect that positively contributes to the elasticity of savings with respect to the rate of return, by inducing revaluations of existing wealth. Although the “wealth” effect reinforces the substitution effect it does not resolve the theoretical ambiguity regarding the sign of the net effect. Empirical estimates range from negative, insignificant or clustered around zero (Blinder and Deaton, 1985; Hall, 1988; Skinner and Feenberg, 1990; Bosworth and Burtless, 1992) to rather large values: 0.2-0.6 (Boskin, 1978; Barro, 1992; Feldstein, 1995). A review of the existing studies on the interest elasticity of savings is provided by Boadway and Wildasin (1995). Despite the uncertainty regarding this elasticity, Elmendorf (1996) underlines that models that are likely to describe the behavior of people that account for most of the aggregate saving generally imply positive interest elasticities. Based on a basic lifecycle model with empirically-supported parameters, Elmendorf (1996) generates an elasticity of about 0.5. However, its magnitude is sensitive to the exact parameter choices. The choice of the elasticity of savings with respect to the rate of return in GreenMod-SoCal is provided in Table 5, which is consistent with the typical values found in the CGE literature.

2.13 Data

The great amount of detail that is incorporated in the typical CGE model requires an equally great amount of data be assessed. The dependencies of all agents and institutions in the model on each other’s decisions and related outcomes, and the simultaneity in decision-making that is implied when solving the model, demand that all data are consistent and in line with the equalities, entities and the definitions that are common to all macroeconomic models. Therefore, it is crucial to collect and present the data in a consistent and structured form. The standard way to do this is in a Social Accounting Matrix, which provides a broad and detailed overview of all flows of commodities, services, production factors, transfers, taxes, investments etc. that are observed in the economy at the moment in time that is used as the benchmark. In this matrix, the same categorization is used as the one used in the model, hence 18 sectors, 18 commodities and 4 economic agents (firms, households, government and the rest of the world) are distinguished.

The data that are used as sources for building the SAM are the Input-Output tables and National Accounts for the year 2004 provided by IMPLAN. The resulting SAM is presented in tables S1-S9. By convention, row entries refer to incoming flows, whereas column entries refer to outgoing flows. By adopting this system, every number in the SAM represents the flow of an economic quantity, and the source (column) and destination (row) can easily be linked. The matrix that is created in this way should satisfy two constraints: first, it should be square such that for every good, sector, agent, etc., both the income and expenditures are presented; and second, the matrix should be balanced, to the extent that the total quantities received should be equal to the total quantities supplied, and hence the sum over a particular row should equal the sum over a particular column.

Different groups of actors in the economy are categorized in different accounts in the SAM: commodities, branches of activity, tax accounts, institutional accounts, a capital account and the Rest of the World are distinguished respectively in the SAM for California.

The commodities account presents an overview of the different categories of supply and demand of commodities in the economy, together with price increases due to taxation. The first building block of this account is the production block in table S2. This table is created based on the supply-table, and one can conclude that the chosen disaggregation over sectors and commodities implies that half of the industrial sectors produce one single commodity, whereas the other half produce several goods. The production block is valued at basic prices. Net taxes on products are, in three categories, separately included and displayed in table S3. Imports are recorded in the Rest of the World (ROW) account, valued at Cost Insurance Freight (cif) prices. Therefore, the sum of every column in the commodities account gives the total supply (domestic and from ROW) of commodities at market prices. Next, in line with this, in the rows of the commodities account, the different demand categories are presented at market prices, for which the data are all obtained from the use-table: first, the intermediate consumption of commodities used in the production process (table S4); second, the final consumption by the households and the government (table S7); and finally, in the capital account the change in inventories and the investment allocation over the commodities are recorded.

The production account summarizes the production process per branch of activity, and defines the inputs used and the outputs resulting from economic activity in each of the 18 sectors. In the production rows, total domestic production for the domestic market is given as well as domestic production for exports, both at basic prices. The production columns present the elements that constitute this domestic production: intermediate consumption and GDP at basic prices. GDP is split into different elements (S6): the paid remunerations of capital (proprietary income) and labor (compensation of employees); taxes on capital and labor; and depreciation, which is included in the row for the capital account.

The various types of taxes that are levied by the government are included in the block to which they apply; total taxes on household’s consumption, local taxes on GFCF and indirect business taxes apply to commodities, and taxes on labor and capital apply to the production block.

Whereas the different elements that constitute GDP are regarded as costs when considering the production account, in the rows corresponding to the factors of production, they are interpreted as income. They define the amount of income that is available to be distributed over the different agents in the economy. This distribution over the four agents is given in the corresponding columns, with households receiving the compensations of employees and households, firms and the ROW receiving the proprietary income.

In the rows of the institutional accounts one can observe that, next to the factor incomes, the agents receive another flow of income that is displayed in the intersection with the institutional accounts themselves. These flows represent current transfers from one unit to another, typically consisting of social benefits, social contributions or current taxes on wealth etc. and include property income. Next to this, the government has another source of income:

the revenues from the different taxes that are levied. The current transfers represent an income for one agent and expenditures for another. When the factor incomes are adapted for net transfers and property income and tax revenues, one finds the net disposable income for the different units. In the columns of firms, households and the government, one can find how the disposable income is spent, respectively. Government and households consume the majority and the remainder is saved.

The capital account consists of different components: depreciation, savings and net lending from the ROW in the row, and investments and changes in inventories in the column. The only entry that is added to these accounts is the one that connects the two elements: the total value of changes in inventories that need to be financed by the difference between total savings and investment plus depreciation.

Finally, the ROW account completes the SAM, including exports, imports, received proprietary income and paid current transfers, and the foreign savings.

Table S1: Social Accounting Matrix for Southern California, in million Dollars

SAM 2004 - Southern California			Commodities																	
			Oilseeds and other agricultural products	Oil and gas	Electric Power	Water	Construction	Manufacturing	Refined Petroleum	All other petroleum and coal products	Petrochemical manufacturing	Industrial gas manufacturing	Air transportation	Rail transportation	Water transportation	Truck transportation	Other transportation	Warehousing and storage	Retail	Miscellaneous
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Commodities	Oilseeds and other agricultural products	1																		
	Oil and gas	2																		
	Electric Power	3																		
	Water	4																		
	Construction	5																		
	Manufacturing	6																		
	Refined Petroleum	7																		
	All other petroleum and coal products	8																		
	Petrochemical manufacturing	9																		
	Industrial gas manufacturing	10																		
	Air transportation	11																		
	Rail transportation	12																		
	Water transportation	13																		
	Truck transportation	14																		
	Other transportation	15																		
	Warehousing and storage	16																		
	Retail	17																		
	Miscellaneous	18																		

Table S2: Social Accounting Matrix for Southern California, in million Dollars

SAM 2004 - Southern California			Commodities																	
			Oilseeds and other agricultural products	Oil and gas	Electric Power	Water	Construction	Manufacturing	Refined Petroleum	All other petroleum and coal products	Petrochemical manufacturing	Industrial gas manufacturing	Air transportation	Rail transportation	Water transportation	Truck transportation	Other transportation	Warehousing and storage	Retail	Miscellaneous
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Production	Agriculture	19	2,934																	12
	Mining	20		4,081				9	273											
	Oil and Gas extraction	21		23	17,781	124														
	Water	22				186														20
	Construction	23					87,554													
	Manufacturing	24		41				78,343	7	2	129	4								891
	Petroleum refineries	25							17,836		1,182									
	All other petroleum and coal products manufacturing	26						2	1	11										
	Petrochemical manufacturing	27						123	281		994									
	Industrial gas manufacturing	28						9				457								
	Air transportation	29											2,937							
	Rail transportation	30												1,448						
	Water transportation	31													729					
	Truck transportation	32														8,755				
	Other transportation	33											184	83	21	132	9,287			
	Warehousing and storage	34																1,881		
	Retail	35																	82,083	
	Miscellaneous	36		27	3,405	2,635		15									745		105	517,186

Table S3: Social Accounting Matrix for Southern California, in million Dollars

SAM 2004 - Southern California — Commodities

			Oilseeds and other agricultural products	Oil and gas	Electric Power	Water	Construction	Manufacturing	Refined Petroleum	All other petroleum and coal products	Petrochemical manufacturing	Industrial gas manufacturing	Air transportation	Rail transportation	Water transportation	Truck transportation	Other transportation	Warehousing and storage	Retail	Miscellaneous
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Production Factors	Employee Compensation	37																		
	Proprietary Income	38																		
	Tax on labour	39																		
	Tax on capital	40																		
Taxes	Local taxes on households consumption	41	43	0	693	137	0	1,724	412	0	0	1	137	23	40	196	111	2	3,813	18,279
	Local taxes on GFCF	42	0	1	0	0	362	48	0	0	0	0	0	0	0	1	0	0	12	90
	Indirect Business Taxes	43	371	599	1,959	171	1,127	6,350	1,534	1	287	70	217	238	35	821	1,654	363	1,702	38,378
Institutional Units	Households	44																		0
	Governments	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Enterprises (Corporations)	46																		
CAPITAL	Investment/Savings	47																		0
	Changes in Inventory	48																		
ROW	Foreign Trade	49	3,461	7,981	12,981	1,372	66,988	67,735	15,125	21	2,536	406	1,762	1,545	471	7,483	7,042	1,486	32,227	294,972
	TOTAL	50	**6,809**	**12,754**	**36,819**	**4,624**	**136,032**	**154,357**	**35,271**	**35**	**5,108**	**936**	**5,218**	**3,318**	**1,295**	**17,388**	**18,820**	**3,532**	**99,741**	**869,828**

Table S4: Social Accounting Matrix for Southern California, in million Dollars

SAM 2004 - Southern California			Production																	
			Agriculture	Mining	Oil and Gas extraction	Water	Construction	Manufacturing	Petroleum refineries	All other petroleum and coal products manufacturing	Petrochemical manufacturing	Industrial gas manufacturing	Air transportation	Rail transportation	Water transportation	Truck transportation	Other transportation	Warehousing and storage	Retail	Miscellaneous
			19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Commodities	Oilseeds and other agricultural products	1	540	0	0	0	40	4,919	0	0	2	0	0	0	0	0	0	0	1	384
	Oil and gas	2	1	361	2,816	0	112	681	8,362	2	15	3	0	1	0	0	30	0	0	179
	Electric Power	3	87	165	7	5	332	8,880	811	1	69	127	19	1	2	25	61	109	1,734	8,501
	Water	4	27	9	32	0	48	130	3	0	1	0	1	1	1	3	16	4	91	1,235
	Construction	5	28	1	838	29	87	1,380	25	0	5	6	4	0	0	19	124	18	461	7,313
	Manufacturing	6	460	295	440	3	8,153	64,019	657	0	93	12	98	87	41	297	245	25	831	17,369
	Refined Petroleum	7	303	292	839	4	1,811	5,101	6,697	12	556	17	1,156	90	43	1,253	1,375	110	865	3,369
	All other petroleum and coal products	8	0	0	0	0	0	16	17	0	0	0	0	0	0	0	0	0	0	0
	Petrochemical manufacturing	9	0	82	7	0	5	3,568	157	0	715	0	0	0	0	0	0	0	0	456
	Industrial gas manufacturing	10	0	18	2	0	0	537	0	0	11	6	0	0	0	1	0	0	0	327
	Air transportation	11	3	2	13	0	55	939	28	0	2	1	3	1	1	14	49	1	95	1,155
	Rail transportation	12	23	25	646	0	137	1,439	42	0	7	0	5	4	0	80	24	1	12	255
	Water transportation	13	3	6	54	0	40	237	34	0	2	0	3	0	0	12	5	0	5	63
	Truck transportation	14	58	52	113	0	1,091	7,992	95	0	20	1	10	6	2	1,323	207	6	158	1,580
	Other transportation	15	8	43	2,603	1	238	2,818	1,301	0	10	3	390	142	249	444	274	20	1,114	6,045
	Warehousing and storage	16	30	22	1	0	3	2,021	52	0	8	6	1	0	2	167	89	0	584	464
	Retail	17	12	29	38	1	10,393	2,911	27	0	10	3	8	2	4	287	88	12	1,695	8,417
	Miscellaneous	18	748	1,513	3,227	22	12,402	92,163	2,589	4	290	148	1,993	309	354	1,939	2,212	538	25,870	232,469

Table S5: Social Accounting Matrix for Southern California, in million Dollars

SAM 2004 - Southern California			Production																	
			Agriculture	Mining	Oil and Gas extraction	Water	Construction	Manufacturing	Petroleum refineries	All other petroleum and coal products manufacturing	Petrochemical manufacturing	Industrial gas manufacturing	Air transportation	Rail transportation	Water transportation	Truck transportation	Other transportation	Warehousing and storage	Retail	Miscellaneous
			19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Production	Agriculture	19																		
	Mining	20																		
	Oil and Gas extraction	21																		
	Water	22																		
	Construction	23																		
	Manufacturing	24																		
	Petroleum refineries	25																		
	All other petroleum and coal products manufacturing	26																		
	Petrochemical manufacturing	27																		
	Industrial gas manufacturing	28																		
	Air transportation	29																		
	Rail transportation	30																		
	Water transportation	31																		
	Truck transportation	32																		
	Other transportation	33																		
	Warehousing and storage	34																		
	Retail	35																		
	Miscellaneous	36																		

Table S6: Social Accounting Matrix for Southern California, in million Dollars

SAM 2004 - Southern California			Production																	
			Agriculture	Mining	Oil and Gas extraction	Water	Construction	Manufacturing	Petroleum refineries	All other petroleum and coal products manufacturing	Petrochemical manufacturing	Industrial gas manufacturing	Air transportation	Rail transportation	Water transportation	Truck transportation	Other transportation	Warehousing and storage	Retail	Miscellaneous
			19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Production Factors	Employee Compensation	37	1,308	859	1,832	56	19,767	65,081	607	1	32	45	1,602	482	95	2,516	7,191	1,470	21,503	221,146
	Proprietary Income	38	1,074	1,359	3,473	67	11,437	21,734	295	0	63	61	314	219	59	1,641	1,879	127	7,358	125,399
	Tax on labour	39	192	126	269	8	2,901	9,551	89	0	5	7	235	71	14	369	1,055	216	3,156	32,455
	Tax on capital	40	16	20	52	1	172	327	4	0	1	1	5	3	1	25	28	2	111	1,887
Taxes	Local taxes on households consumption	41																		
	Local taxes on GFCF	42																		
	Indirect Business Taxes	43																		
Institutional Units	Households	44																		
	Governments	45																		
	Enterprises (Corporations)	46																		
CAPITAL	Investment/Savings	47	189	843	1,771	28	2,433	13,657	165	0	51	49	245	188	43	531	516	81	3,199	68,863
	Changes in Inventory	48																		
ROW	Foreign Trade	49																		
	TOTAL	50	5,110	6,121	19,073	226	71,658	309,852	22,037	21	1,968	495	6,094	1,608	912	10,947	15,467	2,737	68,814	739,331

Table S7: Social Accounting Matrix for Southern California, in million Dollars

SAM 2004 - Southern California			Production Factors				Taxes			Institutional Units			CAPITAL		ROW	
			Employee Compensation	Proprietary Income	Tax on labour	Tax on capital	Local taxes on households consumption	Local taxes on GFCF	Indirect Business Taxes	Households	Governments	Enterprises (Corporations)	Investment/Savings	Changes in Inventory	Foreign Trade	TOTAL
			37	38	39	40	41	42	43	44	45	46	47	48	49	50
Commodities	Oilseeds and other agricultural products	1								862	44		0	16		6,809
	Oil and gas	2								2	11		193	4		12,754
	Electric Power	3								13,819	2,281		0	3		36,819
	Water	4								2,729	293		0	0		4,624
	Construction	5								0	12,889		113,026	0		136,032
	Manufacturing	6								34,406	8,870		14,913	3,046		164,357
	Refined Petroleum	7								8,222	1,988		0	1,198		35,271
	All other petroleum and coal products	8								2	0		0	0		35
	Petrochemical manufacturing	9								0	38		0	81		5,108
	Industrial gas manufacturing	10								12	22		0	1		936
	Air transportation	11								2,743	46		48	19		5,218
	Rail transportation	12								461	56		71	27		3,318
	Water transportation	13								792	35		1	3		1,295
	Truck transportation	14								3,916	182		332	255		17,388
	Other transportation	15								2,221	896		0	0		18,820
	Warehousing and storage	16								42	57		0	0		3,532
	Retail	17								72,091	128		3,697	0		99,741
	Miscellaneous	18								384,756	98,614		28,103	-415		869,828

Table S8: Social Accounting Matrix for Southern California, in million Dollars

SAM 2004 - Southern California			Production Factors				Taxes			Institutional Units			CAPITAL		ROW	
			Employee Compensation	Proprietary Income	Tax on labour	Tax on capital	Local taxes on households consumption	Local taxes on GFCF	Indirect Business Taxes	Households	Governments	Enterprises (Corporations)	Investment/Savings	Changes in Inventory	Foreign Trade	TOTAL
			37	38	39	40	41	42	43	44	45	46	47	48	49	50
Production	Agriculture	19													2,164	5,110
	Mining	20													1,757	6,121
	Oil and Gas extraction	21													1,145	19,073
	Water	22													21	226
	Construction	23													4,104	71,658
	Manufacturing	24													230,435	309,852
	Petroleum refineries	25													3,239	22,037
	All other petroleum and coal products manufacturing	26													8	21
	Petrochemical manufacturing	27													570	1,968
	Industrial gas manufacturing	28													30	495
	Air transportation	29													3,157	6,094
	Rail transportation	30													160	1,608
	Water transportation	31													183	912
	Truck transportation	32													2,192	10,947
	Other transportation	33													5,821	15,467
	Warehousing and storage	34													1,058	2,737
	Retail	35													6,732	68,814
	Miscellaneous	36													215,214	739,331

Table S9: Social Accounting Matrix for Southern California, in million Dollars

SAM 2004 - Southern California			Production Factors				Taxes			Institutional Units			CAPITAL		ROW	
			Employee Compensation	Proprietary Income	Tax on labour	Tax on capital	Local taxes on households consumption	Local taxes on GFCF	Indirect Business Taxes	Households	Governments	Enterprises (Corporations)	Investment/Savings	Changes in Inventory	Foreign Trade	TOTAL
			37	38	39	40	41	42	43	44	45	46	47	48	49	50
Production Factors	Employee Compensation	37														345,594
	Proprietary Income	38														176,559
	Tax on labour	39														50,719
	Tax on capital	40														2,656
Taxes	Local taxes on households consumption	41														25,411
	Local taxes on GFCF	42														514
	Indirect Business Taxes	43														55,880
Institutional Units	Households	44	345,594	102,411						10,626	92,741	31,983	0		11,538	594,891
	Governments	45			50,719	2,656	25,411	514	55,880	51,081	71,586	28,167	0	0	12,746	298,760
	Enterprises (Corporations)	46		70,325							2,658					72,983
CAPITAL	Investment/Savings	47								26,111	5,567	12,832			27,147	164,507
	Changes in Inventory	48											4,225		0	4,225
ROW	Foreign Trade	49		3,823												529,418
	TOTAL	50	345,594	176,559	50,719	2,656	25,411	514	55,880	594,891	298,760	72,983	164,507	4,225	529,418	

3.0 MODEL RESULTS

On June 1, 2005 Governor Schwarzenegger issued Executive Order S-3-05 that acknowledged the vulnerability of the state of California to the impacts of climate change. This EO established GHG emission targets for the state. Building on the Governor's efforts the state legislature passed the California Global Warming Solutions Act (AB32) in August 2006. AB32 established emissions targets and authorized the state Air Resources Board to use market-based incentives to meet the established targets. This section discusses the application of the CGE model to address emissions reductions.

3.1 Policy Alternatives

Policy makers have generally chosen between two types of policies. First, the most commonly used approach has been to establish a standard for the pollution source. These standards either establish a certain level of performance or require a technological standard. Economists have demonstrated that the use of such standards result in the efficient solution only under certain conditions[1].

More recently regulators have used market based incentives as the more desirable policy option. The most notable example is the sulphur dioxide (SO2) market for allowances used in the Clean Air Act Amendments of 1990. Market based incentives use either a quantity-based approach or a price-based approach. The market for SO2 used a quantity-based approach. This approach is generally referred to as a 'cap and trade' system or 'tradable permits'. The essential element of this approach is that the regulators will establish the quantity, or number of allowances, that will be available and then through trading the market will establish the price of the allowance or permit.

Alternatively, the price mechanism relies on the regulator setting a price per unit of emission and then the market will determine the quantity of emission allowances or permits demanded. The price that is set is generally in the form of a tax or a fee. The revenue will then accrue to the regulator to be used to mitigate the damages if needed. Therefore, whether a quantity approach or a price approach is used the resulting market equilibrium will be on the same demand curve.

The success of market based approaches resulted in negotiators of the Kyoto treaty in 1996 to propose the use of a quantity based market approach to meet the targets for carbon dioxide emissions on a global scale. Although the Kyoto Protocols weren't implemented on a global scale, there have been several regional cap and trade markets established. As California has moved forward in establishing targets for emissions reductions and choosing the desired method to implement AB32, the most frequently discussed approach is to develop a cap and trade or quantity based program.

3.2 Policy Counterfactual

The model developed in section 2 will provide the foundation for analyzing the impacts of a climate change policy designed to estimate the sector impacts assuming the policy was in place during the base year. The policy counterfactual will allow us to determine which sectors would have been most impacted had there been a policy in place during the base year.

[1] For a discussion of these conditions see any environmental economics text book. For example, see Tietenberg & Lewis 2009 or Goodstein 2008.

The policy instrument that we will use to develop the counterfactual is a market based incentive using the price mechanism. Essentially we will model the policy as a tax on energy. Although the efficient tax should be placed on the pollutant, CO_2 (or CO_2 equivalent) in this case, we are not able to disaggregate the model sufficiently to evaluate such a tax. Given that the model is static we will assume that the relationship between the production level and the emissions output is constant for the time considered.

Table 6: California Greenhouse Gas Inventory (millions of metric tonnes of CO2 equivalent) - By IPCC Category (millions of metric tonnes of CO2 equivalent)

	California			SoCal	
Balance Category	1990	2004		1990	2004
Petroleum Subtotal	28.10138	30.05919		13.48866	14.42841
Manufacturing Subtotal	23.60957	18.16564		11.33259	8.719505
Mining Subtotal	0.027798	0.127739		0.013343	0.061315
Construction Subtotal	0.665178	0.755596		0.319286	0.362686
Air Trans Subtotal	24.21697	22.21819		11.62415	10.66473
Road Trans					
Truck Subtotal	29.06625	16.26222		13.9518	7.805865
Other Subtotal	101.8628	146.36		48.89414	70.25279
Rail Trans Subtotal	2.312129	3.162489		1.109822	1.517995
Water Trans Subtotal	1.584153	1.29231		0.760394	0.620309
Retail & Warehousing Subtotal	0.680738	0.570915		0.326754	0.274039
Agriculture Subtotal	4.48632	4.819726		2.153434	2.313469
TOTAL	216.6133	243.794		103.9744	117.0211
Total All Sectors	387.7931	436.6734		186.1407	209.6032

Source: Authors calculations based upon data from the California Greenhouse Gas Inventory: By IPCC Category, California Air Resources Board. 8.22.2007.

The focus of the model will be on the impact of the energy tax on energy consumption by sector, the change in CO_2 emissions by sector and the impact on regional gross domestic product. In order to determine these results we needed to include a link to the CO2 emissions from the economic activity (see section 2.10 above). Table 6 provides the baseline data used to determine the emissions factor and to allocate emission reductions by sector for the counterfactual scenario.

The policy scenario that we evaluate is a doubling of the energy tax. The effect of doubling the energy tax is presented in table 7. The results are presented for each sector. The important result of interest in this model is the impact that the tax will have on the CO2 emissions. Table 7 also provides the impact on CO2 emissions for each sector as well as the aggregate reduction in emissions due to the energy tax.

Table 7: Sector Impacts from Doubling Energy Tax (% change)

Sector		ENERGY	CO2EMISSIONS
Agriculture	sec1	-2.66	-2.66
Oil and gas extraction	sec2	-3.37	-3.32
Power generation and supply	sec3	-2.9	-2.92
Water	sec4	-2.30	-2.30
Construction	sec5	-2.01	-2.00
Manufacturing	sec6	-2.78	-2.74
Petroleum refineries	sec7	-13.30	-13.28
All other petroleum and coal products manufactured	sec8	-22.45	-22.44
Petrochemical manufacturing	sec9	-8.63	-8.63
Industrial gas manufacturing	sec10	-3.97	-3.91
Air transportation	sec11	-5.29	-5.29
Rail transportation	sec12	-2.58	-2.57
Water transportation	sec13	-2.89	-2.89
Truck transportation	sec14	-3.09	-3.09
Other Transportation	sec15	-3.29	-3.29
Warehousing and storage	sec16	-3.81	-3.80
Retail	sec17	-2.51	-2.50
Miscellaneous	sec18	-2.20	-2.17
Regional GDP			-0.19
CO2EMIST (total)			-6.90

As expected, the greatest impact is found in the energy producing sectors that would be more directly impacted from the tax. Sectors that use energy as a primary input into the production process such as air transportation and truck transportation are more significantly impacted than sectors such as retail. Overall, doubling the tax on energy will result in a decrease in carbon dioxide emissions in southern California of almost seven percent. This decrease in CO2 emissions will cost the economy approximately 0.2 percent of the regional GDP. This would be a cost of $174 per ton of CO2 removed.

4.0 Conclusions and Future Research

The results of this model are based upon a static CGE model with a number of simplifying assumptions. Comparing the finding that to remove a ton of CO2 would cost $174 we see that the use of an energy tax would be quite expensive compared to what is observed as the price of a permit to emit a ton of carbon on markets for carbon in Europe and the Chicago Board of Trade. This model demonstrates that the sector specific results from a climate change policy such as an energy tax can be estimated and provide insight for policy makers. However, it is important to recognize the limitations on the results.

There are a number of improvements that can be made to this model. First, the sectors of the economy could be modelled to consider imperfectly competitive structures where appropriate. Assuming markets are perfectly competitive improves the tractability of the model but may not capture all the strategic interactions between the sectors.

Second, it would be helpful to expand the number of households included in the analysis. This version of the model has one household sector. Expanding the number of households would allow policy makers to consider some environmental justice issues with a policy as well as consider how the benefits and costs are distributed across households.

Third, a static model is limited in its ability to discuss results that occur in a temporally. A dynamic CGE model would be able to more accurately capture the policy targets that are included in climate change legislation. For example, to meet the target of reducing CO2 emissions to 1990 levels by 2020 requires meeting various targets along the way. A dynamic model would permit policy makers to better understand the economic consequences that occur as targets are met in 2012, 2015, etc.

Finally, using more current data to calibrate the model would result in capturing more recent advances in technology, management practices as well as consumer preferences for ‘green’ products as they evolve. Updating the base year would allow the model to capture structural changes that have occurred due to the recent economic recession. As the model is improved along these dimensions it will be more useful for analyzing the impacts of more complex climate change policy options.

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