`

Economic Growth and Greenhouse Gas Mitigation in California

David Roland-Holst[†]
UC Berkeley

August 2006

[†] The author is Adjunct Professor of Agricultural and Resource Economics at UC Berkeley and Professor of Economics at Mills College. Financial support from the Energy Foundation is gratefully acknowledged. Thanks are also due Chris Busch, Alex Farrell, Michael Hanemann, Skip Laitner, Jason Mark, and Marcus Schneider for helpful insights and comments, and to Fredrich Kahrl for excellent research assistance. Opinions expressed here are the author's and should not be attributed to his affiliated institutions.

`

EXECUTIVE SUMMARY

The California economy has an enviable record of technological progress, and the challenge presented by climate change is a new opportunity for the state to demonstrate its talent for combining advances in public policy and private sector innovation to enhance environmental quality and economic growth.

This research note offers preliminary results on the link between greenhouse gas (GHG) abatement strategies and economic growth from on-going research with a forecasting model of the California economy. The Berkeley Energy and Resources (BEAR) Model is a detailed empirical simulation tool that can evaluate the complex linkages between climate policy and economic activity. In the analysis presented here, eight targeted GHG emission policies are combined with an overall cap to meet the state's targets for 2020. No specific implementation of the cap is assumed; these results can be interpreted as the result of an efficient combination of policies. Examining alternative scenarios for state climate policy over the next fifteen years, a few salient conclusions emerge:

1. California's GHG targets are attainable, but too ambitious to be met by voluntary initiative. Policy action to meet the targets should be relatively inclusive, with mandatory participation by all sectors representing a significant share of emissions.
2. An Emissions Cap, supported by regulatory and market-based implementation programs, can return California's GHG emissions to 1990 levels by 2020 and stimulate the state economy.
3. Climate policies that create direct incentives for industries to invest in new technologies can provide additional stimulus for new employment and growth.

`

Table ES-1: Macroeconomic Impacts of 8 CAT policies plus a 2020 GHG Cap*
*(1990 GHG Emissions Levels by 2020)

Annual Impact	8 CAT policies + Cap	8 CAT policies + Cap w/Innovation Incentives
Gross State Product (2006 dollars) *% change from 2020 baseline*	**+$60 Billion** *(+2.4%)*	**+$74 Billion** *(+3.1%)*
Employment (thousands) *% change from 2020 baseline*	**+17** *(+.08%)*	**+89** *(+0.44%)*

The findings reported here indicate that California can establish global leadership in growth-oriented climate policy and energy innovation. Well-designed and implemented strategies can bring forth the state's enormous innovation potential and apply it to one of the most compelling challenges of our era.

Notes on the policy scenarios and results:

The policy scenarios included here are designed to represent important elements of California's climate action policies that are under development, including AB32 ("The California Global Warming Solutions Act") as well as several Climate Action Team (CAT) measures. One of the key findings of this report is that regulatory and market-based strategies are complementary; each excels at achieving different forms of mitigation. We show how all significant stationary source emitters could contribute to meeting the state's reduction goals, either through inclusion in a cap, an offset mechanism, or through regulatory programs.

The analysis presented here is an update to a study released in January that concluded achieving half the 2020 targets would promote economic growth in California (Roland-Holst, 2006). This study extends the earlier work to meet all of the 2020 targets, and confirms the earlier conclusion about economic benefits.

The positive economic results are derived from two primary sources: savings from improvements in energy efficiency and reduced energy bills that offset the cost of achieving emission reductions and, in related policy scenarios, the benefits of investing in technologies for innovation. California has a long history of leadership in both of these areas, and continuing along these lines will yield positive economic and environmental benefits for the state.

`

While our results are encouraging, they may be overly conservative for several reasons. First, we do not consider spontaneous technological innovation in this version of the BEAR model, and only a few GHG mitigation technologies are represented explicitly, although these features will be added to later versions of the model. Second, only 8 of 34 Climate Action Team policies are modeled here, and several with significant mitigation potential are not considered. Including these would reduce the estimated mitigation burden and attendant costs for industries covered in this analysis. Third, the results consider only limited potential for technical and fuel substitution (e.g., the substitution of renewable energy sources for fossil fuel power plants). Finally, we do not allow for lower-cost reductions from offsets or links to other carbon regimes to replace reductions from the sources considered here.

`

CONTENTS

`

1. INTRODUCTION

Climate change will have serious impacts on the state of California and is now widely recognized as an important global challenge. As the largest state economy in the world's largest economy, and as an economy built upon innovation, California is in a special position to lead climate change policy by example and by insight. The state government has already contributed to this effort, and the results reported here join a body of previous research into how climate policies can be formulated to encourage economic growth. In this paper, a state-of-the-art economic model is used to assess potential state policies for managing greenhouse gas (GHG) emissions, meeting the 2020 GHG target while promoting economic growth. These results elucidate detailed linkages between policy and behavior, efficiency and growth. Generally speaking, it is apparent from this analysis that growth and environmental objectives are not only compatible, but can be mutually reinforcing in the right policy environment.

The complexities of today's global economy make it very difficult for intuition or rules-of-thumb to reliably support policy-making, and using inadequate analytical tools or weak comparison cases would be at best sub-optimal and at worst misleading. Market interactions are so pervasive in determining economic outcomes that more sophisticated empirical research tools are needed to improve visibility for both public and private sector decision makers. The preferred tool for detailed empirical analysis of economic policy is now the Calibrated General Equilibrium (CGE) model. It is well suited to GHG research because it can detail structural adjustments within economies and elucidate their interactions in external markets. The CGE research tool used for this assessment, the Berkeley Energy and Resources (BEAR) model, was developed to evaluate the economic impacts of energy and climate polices in California and contains a level of detail and overall structure specifically suited to this task. However, innovation processes are not captured in this version of the BEAR model and only a few GHG mitigation technologies are represented explicitly. Further work is underway to add these features, but their absence here means that the results may be overly conservative, i.e. the costs of mitigation could be lower than estimated here. A general overview of the BEAR model is provided in Section 2 to facilitate

`

interpretation of the results that follow. Section 3 presents the policy scenarios evaluated in this report, with results in Section 4 and conclusions in Section 5.

2. OVERVIEW OF THE BEAR MODEL

The Berkeley Energy and Resources (BEAR) model is in reality a constellation of research tools designed to elucidate economy-environment linkages in California. The schematics in Figures 2.1 and 2.2 describe the four generic components of the modeling facility and their interactions. This section provides a brief summary of the formal structure of the BEAR model.[1] For the purposes of this report, the 2003 California Social Accounting Matrix (SAM), was aggregated along certain dimensions. The current version of the model includes 50 sectors aggregated from the original California SAM. The equations of the model are completely documented elsewhere, and for the present we only discuss its salient structural components.

2.1. Structure of the CGE Model

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

The role of markets is to mediate exchange, usually with a flexible system of prices, the most important endogenous variables in a typical CGE model. As in a real market economy, commodity and factor price changes induce changes in the level and composition of supply and demand, production and income, and the remaining endogenous variables in the system. In CGE models, an equation system is solved for prices that correspond to equilibrium in markets and satisfy the accounting identities

[1] See Roland-Holst (2005) for a complete model description.

`

governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the economywide (and regional) effects of alternative policies or external events.

The distinguishing feature of a general equilibrium model, applied or theoretical, is its closed-form specification of all activities in the economic system under study. This can be contrasted with more traditional partial equilibrium analysis, where linkages to other domestic markets and agents are deliberately excluded from consideration. A large and growing body of evidence suggests that indirect effects (e.g., upstream and downstream production linkages) arising from policy changes are not only substantial, but may in some cases even outweigh direct effects. Only a model that consistently specifies economywide interactions can fully assess the implications of economic policies or business strategies. In a multi-country model like the one used in this study, indirect effects include the trade linkages between countries and regions which themselves can have policy implications.

The model we use for this work has been constructed according to generally accepted specification standards, implemented in the GAMS programming language, and calibrated to the new California SAM estimated for the year 2003.[2] The result is a single economy model calibrated over the fifteen-year time path from 2005 to 2020.[3] Using the very detailed accounts of the California SAM, we include the following in the present model:

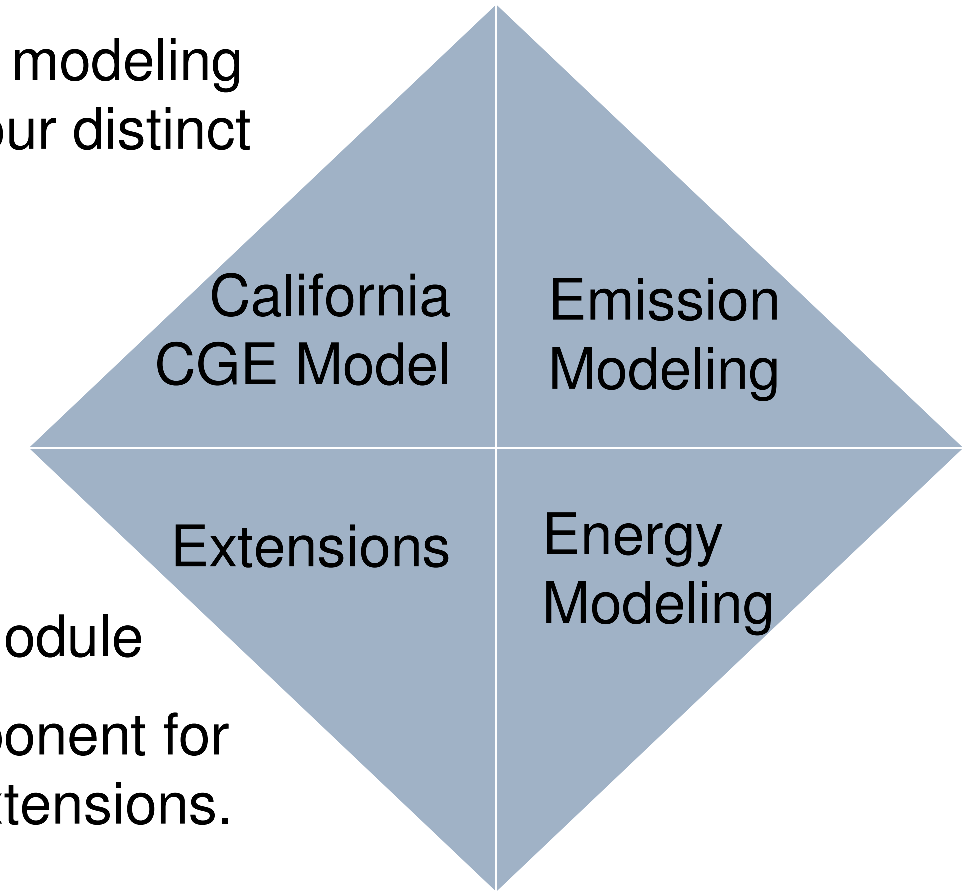
[2] See e.g. Meeraus et al (1992) for GAMS Berck et al (2004) for the California SAM.

[3] The present specification is one of the most advanced examples of this empirical method, already applied to over 50 individual countries or combinations thereof (see e.g. Francois and Roland-Holst, 2000; Lee and Roland-Holst, 1995, 2000, 1998ab; Lee et al., 1999).

Figure 2.1: Component Structure of the Modeling Facility

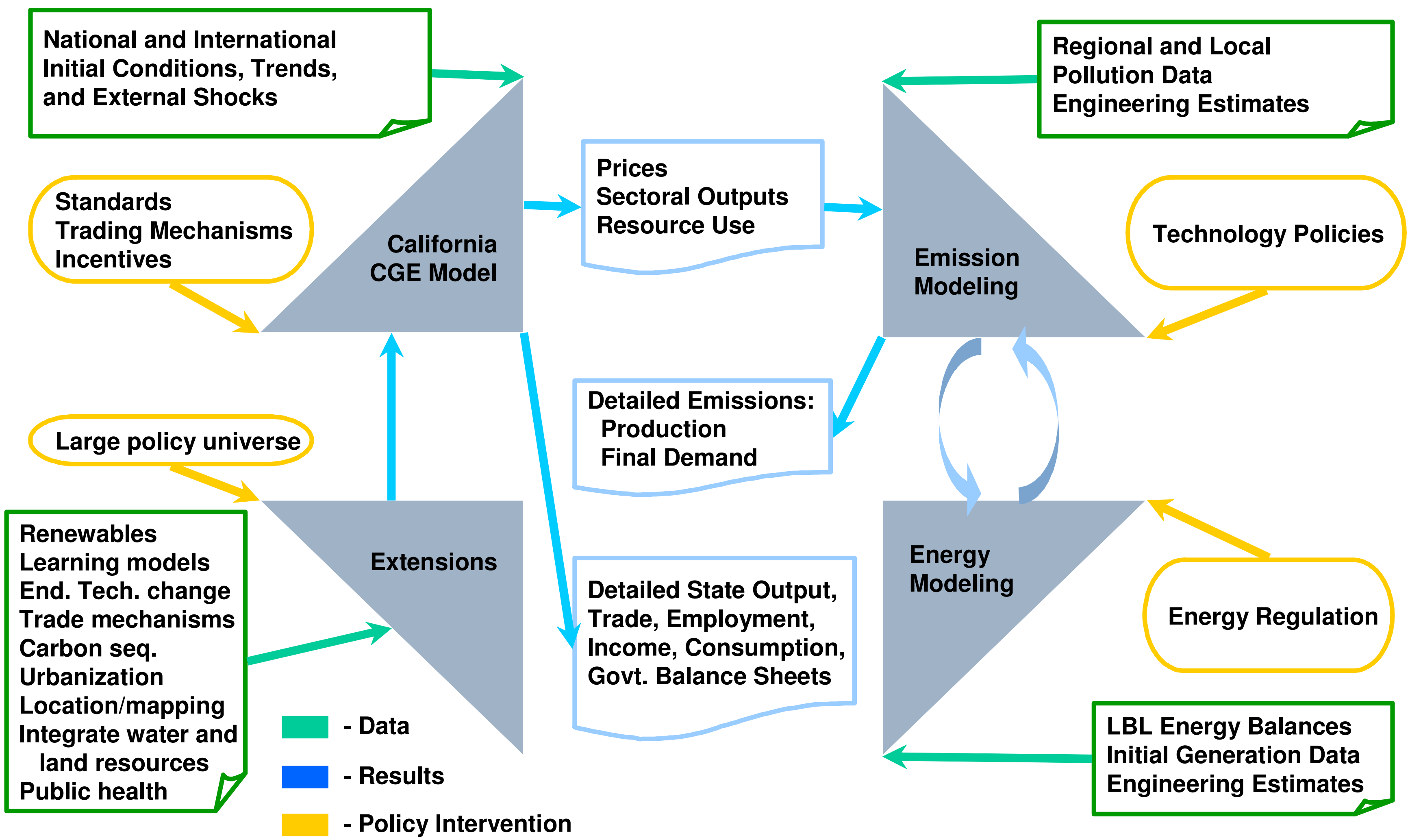
Development of the California modeling capacity is proceeding in four distinct component areas.

1. core CGE model
2. emissions module
3. energy generation module
4. a separate component for developing extensions.



`

Figure 2.2: Schematic Linkage between Model Components



`

2.2. Production

All sectors are assumed to operate under constant returns to scale and cost optimization. Production technology is modeled by a nesting of constant-elasticity-of-substitution (CES) functions. See Figure A1.1 for a schematic diagram of the nesting.

In each period, the supply of **primary** factors — capital, land, and labor — is usually predetermined.[4] The model includes adjustment rigidities. An important feature is the distinction between old and new capital goods. In addition, capital is assumed to be partially mobile, reflecting differences in the marketability of capital goods across sectors.[5]

Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply (zero-profit) conditions in all markets.

2.3. Consumption and Closure Rule

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

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

The current account surplus (deficit) is fixed in nominal terms. The counterpart of this imbalance is a net outflow (inflow) of capital, which is subtracted (added to) the domestic flow of saving. In each period, the model equates gross investment to net saving (equal to

[4] Capital supply is to some extent influenced by the current period’s level of investment.

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

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

`

the sum of saving by households, the net budget position of the government and foreign capital inflows). This particular closure rule implies that investment is driven by saving.

2.4. Trade

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

2.5. Dynamic Features and Calibration

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

2.6. Capital accumulation

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

`

2.7. The putty/semi-putty specification

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

2.8. Dynamic calibration

The model is calibrated on exogenous growth rates of population, labor force, and GDP. In the so-called Baseline scenario, the dynamics are calibrated in each region by imposing the assumption of a balanced growth path. This implies that the ratio between labor and capital (in efficiency units) is held constant over time.[7] When alternative scenarios around the baseline are simulated, the technical efficiency parameter is held constant, and the growth of capital is endogenously determined by the saving/investment relation.

2.9. Modelling Emissions

The BEAR model captures emissions from production activities in agriculture, industry, and services, as well as in final demand and use of final goods (e.g. appliances and autos). This is done by calibrating emission functions to each of these activities that vary depending upon the emission intensity of the inputs used for the activity in question. We model both CO2 and the other primary greenhouse gases, which are converted to CO2 equivalent. Following standards set in the research literature, emissions in production are modeled as factors inputs. The base version of the model does not have a full representation of emission reduction or abatement. Emissions abatement occurs by substituting additional labor or capital for emissions when an emissions tax is applied. This is an accepted modeling practice, although in specific instances it may either understate or overstate

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

`

actual emissions reduction potential.[8] In this framework, mission levels have an underlying monotone relationship with production levels, but can be reduced by increasing use of other, productive factors such as capital and labor. The latter represent investments in lower intensity technologies, process cleaning activities, etc. An overall calibration procedure fits observed intensity levels to baseline activity and other factor/resource use levels. In some of the policy simulations we evaluate sectoral emission reduction scenarios, using specific cost and emission reduction factors, based on our earlier analysis (Hanemann and Farrell: 2006).

The model has the capacity to track 13 categories of individual pollutants and consolidated emission indexes, each of which is listed in Table 2.1 below. Our focus in the current study is the emission of CO2 and other greenhouse gases, but the other effluents are of relevance to a variety of environmental policy issues. For more detail, please consult the full model documentation.

Table 2.1: Emission Categories

Air Pollutants		
1.	Suspended particulates	PART
2.	Sulfur dioxide (SO_2)	SO2
3.	Nitrogen dioxide (NO_2)	NO2
4.	Volatile organic compounds	VOC
5.	Carbon monoxide (CO)	CO
6.	Toxic air index	TOXAIR
7.	Biological air index	BIOAIR
Water Pollutants		
8.	Biochemical oxygen demand	BOD
9.	Total suspended solids	TSS
10.	Toxic water index	TOXWAT
11.	Biological water index	BIOWAT
Land Pollutants		
12.	Toxic land index	TOXSOL
13.	Biological land index	BIOSOL

[8] See e.g. Babiker et al (2001) for details on a standard implementation of this approach.

`

3. SCENARIOS FOR GROWTH AND CLIMATE ACTION

Given the complexity of the GHG emissions challenge and the underlying economy, policy makers have many choices before them. Of course the appeal of diversity is offset by the same complexity and the prospect of divisive interests, but in this policy arena there is broad awareness of what constitute better practices for efficiency and political feasibility. In this section, we offer examples of policy scenarios representing primary elements of California's GHG policy dialogue, including several Climate Action Team measures and a scenario that reflects salient features of AB32, a climate action bill before the state legislature this summer. The generic policy types we assess are summarized in the Table 3.1. The specific scenarios are described in greater detail below.

3.1. Baseline

The first scenario we examine is a calibrated Baseline for the BEAR model, taking explicit account of state projections of anticipated improvements in statewide energy efficiency. For reference, this is contrasted to a "business as usual" (BAU) scenario that holds efficiency levels constant from the base year (2005) to the end of the forecast interval (2020). Both the BAU and Baseline scenarios are calibrated to the same official (California Department of Finance) projected growth rates, but the Baseline also incorporates California Energy Commission projections for improvements in energy efficiency. This Baseline is then used as the dynamic reference path for evaluating the rest of the scenarios below.

3.2. Climate Action Team (CAT) Recommendations

In January of 2006, the California Environmental Protection Agency released a set of GHG mitigation policies recommended to the California executive and legislature for implementation to meet the 2010 and 2020 emission targets. The policies, formulated and assessed by a special Climate Action Team, represent the core of new public policy

`

initiatives for attaining the targets. We assess a prominent subset of these policies for inclusion in the BEAR scenarios.[9]

Table 3.1: Generic Policy Summary

1. **Baseline**
   This scenario incorporates existing policies and CEC projections for autonomous energy efficiency gains by firms and households. It is the reference trend for evaluating the next three scenarios.

2. **Climate Action Team (CAT) Recommendations**
   This policy scenario incorporates eight of the leading recommendations of the California Climate Action Team (CalEPA:2006). These policies have already been modelled by BEAR and are reported in greater detail elsewhere (Hanemann and Farrell:2006).

3. **Emissions Cap**
   The basic regulatory policy considered in this report, this binds defined industry groups to the state's 2020 GHG target, with a linear phase-in from 2012. Aggregate emissions are limited for industries in the group – either because of constraints on individual sectors or across the entire group with emissions trading. Any revenues from the allocation and exchange of emissions allowances are assumed to accrue to emitters.

4. **Emissions Cap and Innovation**
   This scenario replicates the previous one, with the important behavioural restriction that revenues from the allocation and exchange of emissions allowances are ploughed back as investment in new technology that raises productivity and reduces emissions intensity.

3.3. Emissions Caps

Meeting an aggregate GHG target or cap can be accomplished through direct regulation, market-based regulation, or a combination of the two. For convenience and clarity, this

[9] This subset of policies was analyzed in the report released in January (Roland Holst, 2006), and they achieve about half of the emission reduction targeted for 2020. The other scenarios in this study extend the previous analysis to meet the full emission reduction target for 2020.

`

discussion concentrates on market-based approaches.[10] Market mechanisms recognize the incentive properties of private agency, and thereby achieve efficiency in very complex resource allocation problems. Public policies that pursue social objectives can take advantage of this by conferring property rights on social resources like clean air. In the area of climate policy, a large family of policies strives to enlist market mechanisms to mitigate GHG emissions without undue adjustment costs. So-called cap and trade policies are a standard example of this, where a limit is set on some emissions aggregate and property rights to these emissions are conferred on private parties.[11] When properly designed, the trading mechanisms that ensue from these arrangements can efficiently value and reward socially desirable behavior, leading to the intended policy outcome with a minimum of intervention and its attendant public costs.

Despite their intuitive appeal, however, Emissions Caps are complex, and their behavioral properties depend on a variety of important design characteristics.[12] We summarize the main ones in Table 3.2 below, and then describe how Scenario 3 conforms to them.

For this preliminary application of the BEAR model, a relatively simple example of Emissions Caps has been chosen with Assembly Bill 32 in mind. In particular, we consider a cap dictated by the state's 2020 GHG mitigation objectives, with the policy going into effect in 2012 as proposed by a legislative initiative (AB32) currently under consideration in Sacramento. Because of this timetable, we do not consider the 2010 GHG target to be binding. The current bill is not precise about phasing in the cap, but we assume linear progress from Baseline 2012 emissions to the 2020 target over nine years. The scope of emission is all GHGs from sources to be regulated, and these are chosen progressively across three experiments. In other words, we consider a sequence of increasingly inclusive industry groups, chosen in order of emission intensity. Following the recommendation of Burtraw et al (2006), we consider only stationary sources and designate Load Serving Entities (LSE's) for emissions associated with electricity generation.[13]

[10] See e.g. Montero (1999) and Teitenberg (2003), Harrison and Antweiler (2003).

[11] Cap and trade policies, in California and elsewhere have been discussed extensively elsewhere. See e.g. Burtraw and Palmer (2004). Center for Clean Air Policy (2005), Farrell and Lave (2004), Nordhaus and Danish (2003), and Stavins (2003). Pew (2006) provides a convenient starting point in this policy literature.

[12] For a comprehensive review of these, the reader should consult Burtraw et al (2006).

[13] In light of recent policy dialogue, a note on the electricity sector may be in order. In the present work, and the detailed sectoral analysis that will follow over the next few months, we neither found and nor do we anticipate significant price risks in this sector as a result of emissions compliance. In the European carbon trading scheme, for example, price uncertainty has arisen not from the regulatory system, but from external energy markets. Likewise, we believe imported energy dependence is the greatest threat to the purchasing power of electricity users. The efficiency-

`

From the present 50 sector BEAR aggregation, we designate three alternative potential groups for the cap scheme (Table 3.3). These alternatives for the scope of coverage can be thought of "meso" level regulation. In the present version of BEAR, we model sectors (industries), but not individual firms (micro level). The sectoral analysis allows for some degree of heterogeneity between sectors, in contrast to the economywide (macro) approach. When BEAR's data resources have been extended to capture within-sector heterogeneity, we will take a more micro approach to regulatory analysis.

After scope, the allocation mechanism is the most important structural and behavioral feature of a Emissions Cap program.[14] In the present scenario, we assume that emission rights are allocated annually and on the basis of prior annual average energy fuel use. This is a common if imperfect proxy for carbon emission potential, neglecting potential in some important Non-CO2 categories. For the present, however, it provides a serviceable standard. Another important property of allocation is the means by which initial and final revenues from emissions rights are assigned. Rights can be awarded *gratis* or auctioned; revenues from selling them can accrue directly to rights holders or to financial intermediaries. In the present case, we assume rights are auctioned efficiently (i.e. at ex post market values) and their revenues accrue completely to original rights holders. Put differently, revenues from sale of permits to emit greenhouse gases are returned to industry with the amount going to different sectors of the economy proportional to their different baseline emissions levels. This is a form of balance sheet protection. Industry must pay for emissions permits, but they receive substantial offsetting revenue, protecting industry output and production levels.

To summarize how the Emissions Cap system works: An aggregate emissions target or cap is defined with a rule for allocating it across regulated industries. In Scenarios 3-5, the cap applies to the aggregate of all emissions by the target group (1,2,3, etc.). Emissions rights will be traded against the aggregate constraint, reallocating them among polluters according to baseline efficiency and generating premia if the cap constraint is binding. Relative industry efficiency levels are calibrated from baseline costs and factor/emissions shares. For net buyers of permits, these costs are passed on to prices, which affect demand for their products, profitability, and output.

It can be noted that this approach, as well as the larger universe of cap-and-trade policies, can be seen as equivalent to a number of other regulatory approaches. In fact, the policy

---

oriented policies discussed here are intended to reduce that threat. For more on these topics, see e.g. Kartha et al (2004) Hoffert et al (1998).

[14] See, e.g. Fisher and Fox (2004). Ono (2002), and Palmer et al (2005).

`

we model can simply be conceived of as the most economically efficient approach for achieving compliance under each cap scenario, based on the assumptions of each simulation. Indeed, several alternative policy formulations could be compared to identify which achieves the desired emissions outcome more efficiently. Representative policy options include:

1. An emissions cap program for all of the sectors included in the analysis.
2. Perfectly informed regulators implementing sector-specific policies with perfect enforcement and no transaction costs.
3. A target applied to some subset of the sectors included in the analysis, plus an offset program that includes all the remaining sectors.
4. An emissions fee applied at the level of the allowance price determined for each year.
5. Various combinations of regulations, emissions cap, and offset programs.

Other relevant aspects of Emissions Cap policies are Banking, Safety Valves, Linkage, and Economic Justice. None are considered here, but only to keep the present discussion manageable. In future applications, all these features can and will be assessed with BEAR.[15]

[15] On these extensions, see e.g. Rubin (1996), Shennach (2000)

`

Table 3.2: Anatomy of Emissions Cap Policies

1. **Scope:**
   There are two components to the scope of a cap and trade scheme: Which emissions and which entities are to be covered by the policy. The first of these is self-evident, and depends on the target for environmental mitigation (GHG, toxics, particulates, etc.).
   In the second category, there are many practical issues of monitoring, regulation, and incentives. A basic distinction is usually made between upstream (resource oriented), and downstream (end use) entities. For example, to manage carbon emissions, one could regulate fuel producers or consumers.
2. **Allocation:**
   This is the rule by which property rights are assigned. For example, in a cap and trade scheme, emission rights are usually a privately tradable financial asset. How these are allocated policy inception obviously influences private economic behaviour.
3. **Banking:**
   This term refers to the potential for inter-temporal transfer of pollution rights. In an uncertain and cyclical economic environment, banking can improve efficiency.
4. **Safety Valves:**
   These mechanisms permit conditional and temporary flexibility in emission constraints (caps). Understandably, they have complex behavioural properties, including risks of moral hazard and market manipulation, but they can also improve prospects for policy adoption and sustainability.
5. **Linkage:**
   This term refers to interactions between different policies, either in different places or contexts.
6. **Justice:**
   Policies toward the economy and environment can have many welfare implications and should be designed to be equitable.

`

Table 3.3: Alternative Industry Emission Groups

1. **Group 1: First Tier Emitters**

A04DistElc	Electricity Suppliers
A17OilRef	Oil and Gas Refineries
A20Cement	Cement

2. **Group 2: Second Tier Emitters**

A01Agric	Agriculture
A12Constr	Construction of Transport Infrastructure
A15WoodPlp	Wood, Pulp, and Paper
A18Chemicl	Chemicals
A21Metal	Metal Manufacture and Fabrication
A22Aluminm	Aluminium Production

3. **Group3: Other Industry Emitters**

A02Cattle	Cattle Production
A03Dairy	Dairy Production
A04Forest	Forestry, Fishery, Mining, Quarrying
A05OilGas	Oil and Gas Extraction
A06OthPrim	Other Primary Activities
A07DistElec	Generation and Distribution of Electricity
A08DistGas	Natural Gas Distribution
A09DistOth	Water, Sewage, Steam
A10ConRes	Residential Construction
A11ConNRes	Non-Residential Construction
A13FoodPrc	Food Processing
A14TxtAprl	Textiles and Apparel
A16PapPrnt	Printing and Publishing
A19Pharma	Pharmaceuticals
A23Machnry	General Machinery
A24AirCon	Air Conditioner, Refrigerator, Manufacturing
A25SemiCon	Semiconductors
A26ElecApp	Electrical Appliances
A27Autos	Automobiles and Light Trucks
A28OthVeh	Other Vehicle Manufacturing
A29AeroMfg	Aeroplane and Aerospace Manufacturing
A30OthInd	Other Industry

3.4. Climate Policy for Innovation and Growth

This type of scenario is based on the Emissions Cap standard, but incorporates an important behavioral rule difference. Under this arrangement, emission allowances are assigned with the proviso that the revenues from the allocation and exchange of allowances must be ploughed back as investments in new technology that raises energy efficiency and reduce emissions intensity. This approach offers the same balance sheet

`

protection as revenue recycling, but orients firm's strategic opportunities in a way that promotes sustained productivity growth. It also strengthens the incentive for less efficient firms to innovate rather than simply buy permits, i.e. find permanent rather than a temporary solution to firm-level pollution intensity.[16] This type of behavioral incentive could be enacted through tax breaks or investment subsidies, for example.

4. SIMULATION RESULTS AND DISCUSSION

Before discussing the simulation results in detail, it should be noted that we also consider a series of sub-scenarios that represent different scope of coverage and in combination with other forward-looking mitigation policies. To be more precise, in the Emissions Cap category we examine progressive sector coverage, including Groups 1, 2, and 3 in an expanding set of policy experiments. While it is very difficult to estimate the administrative cost of expanding scope, it is useful to see the implications for sectoral efficiency levels. Secondly, we evaluate every other scenario in combination with the eight CAT policies mentioned above. However, more than two dozen Climate Action Team policies and measures are not modeled here, including several large contributors of emissions reductions such as the Renewable Portfolio Standard. Including those policies would reduce the reduction burden on the industries capped in this analysis, and therefore reduce their compliance costs. It is apparent from the results below that climate action needs to be engaged on several regulatory fronts simultaneously.

4.1. Scenario 1: Baseline

The first scenario we examine is a calibrated Baseline for the BEAR model, taking explicit account of state projections of anticipated improvements in state energy efficiency. For reference, this can be contrasted with a "business as usual" (BAU) scenario that holds emission intensity levels constant from the base year (2005) to the end of the forecast interval (2020). Both the BAU and Baseline scenarios are calibrated to the same officially (California Department of Finance) projected GSP growth rates, but the Baseline incorporates more optimistic (California Energy Commission) projections for improvements in energy efficiency and emission intensity. This Baseline is then used as the dynamic

[16] There is an extensive and positive literature on innovation potential and emissions control. See e.g. Fisher et al (2003), Harrison and Antweiler (2003), Kerr and Newell (2003), Milliman and Prince (1989), Norberg-Bohm (1999), Popp (2003), and Taylor et al (2003).

`

reference path for evaluating alternative policy initiatives and changing external conditions over the same period (2005-2020).[17]

4.2. Scenario 2: Climate Action Team Recommendations

As noted above, this scenario incorporates eight leading policy recommendations made by the Climate Action Team (CalEPA:2006). These adopt a direct regulation approach to reducing GHG emissions. The specific policies are listed in the following table:

Table 4.1: CAT Scenario Component Policies

1. Building efficiency policies already underway
2. Vehicle GHG policies already underway
3. Refrigerant Process Efficiency
4. Cement blending and efficiency measures
5. Manure Management
6. Semiconductor Industry Targets
7. Landfill Management
8. Afforestation

See Roland-Holst (2006) for a more detailed explanation of these components and the corresponding BEAR results.

4.3. Scenarios 3-5: Growth Neutrality with Climate Action

These scenarios represent a reference case, assuming California meets its 2020 goals for GHG mitigation. Any revenues from the allocation and exchange of emission allowances are distributed back to the sectors generating the emissions. As a result, there is no significant change in the pattern of real outputs. Using a simulation model like BEAR, this can be done by computing, at the individual sector level, the efficiency growth rates needed to attain GHG goals without reducing output or employment. This kind of simulation is particularly useful for policy analysis, since it provides an explicit way of representing adjustments implied by reconciling diverse interests. In the present case, these can be seen as one way of meeting the state's goals for GHG reduction while maintaining economic wellbeing.

[17] This baseline is explained in greater detail, along with source data, in Roland-Holst (2006).

`

4.4. Scenarios 6-7: Climate Policy for Innovation and Growth

As explained in the last section, the generic policy considered here builds on the prior scenarios for an emissions cap, but it introduces a specific rule for allocating recycled net revenues from the allocation and transfer of emission allowances. In particular, this rule stipulates that firms must re-invest their proceeds in new capital equipment that raises energy efficiency and reduces emissions intensity. We do not specify the particular technologies in which firms invest, only that these investments increase factor productivity.

This investment promotion approach is designed to overcome a variety of residual incentive issues in Emissions Cap systems. In particular, it might be desirable to reduce the incentive to transfer emission premia outside the target sector, e.g. to financial intermediaries who make little or no direct contribution to sectoral or economywide average emissions. Secondly, investment promotion presents less efficient firms with an alternative to the short term fix of buying permits. As more efficient firms experience diminishing returns to their new investments, the cost of capital will fall and make innovation more attractive to less efficient firms. Indeed, there may be conditions under which investment subsidies to this group could be justified, as long as they are financed from the same pool of emission premia.

In any case, Scenarios 6-7 assume recycled revenue accruing within the controlled emission group is invested in new capital, and that these technologies raise capital factor productivity by 2% annually.[18] Scenario 6 applies the cap to sector groups 1-3, while Scenario 7 provides for inclusion of *all* sectors in the state economy. The latter case represents an interesting thought experiment since it levels the playing field by holding all firms that emit greenhouse gasses responsible for meeting for the cap on emissions. While this might be the fairest possible approach, it is also the most expensive to administer. Following basic economic logic, it also leads to the most favorable economic impact from an overall, economy-wide perspective.

[18] This figure is relatively conservative by comparison to the state's historical experience, with average total factor productivity growth of 2-3 percent.

`

4.5. Results and Discussion

In summary, the following seven policy scenarios are analyzed:

1. Baseline (no emission reduction target) [1]
2. 8 CAT policies (direct regulation) [2}
3. CAT policies plus emission cap to meet remainder of 2020 target
    a. Industries in Group 1 covered by an aggregate cap [3]
    b. Industries in Groups 1 and 2 covered by an aggregate cap [4]
    c. Industries in Groups 1, 2 and 3 covered by an aggregate cap [5]
4. 8 CAT policies plus emission cap on industries in Groups 1, 2 and 3 with revenues recycled into innovation investment [6]
5. 8 CAT policies plus emission cap on all emitting industries with revenues recycled into innovation investment [7]

Table 4.2 presents aggregate economic impacts for Scenarios 2 - 7, displayed as percentage changes with respect to the Baseline (1) in the final year (2020).

The CAT scenario (2) was discussed in detail in our January report and it suffices here to note only its general characteristics. Implementing these eight CAT policies has the potential to achieve about half the targeted 2020 emissions reductions, while at the same time stimulating state output and employment. The economic stimulus results from the fact that demand is diverted to more California-intensive expenditure and energy efficiency saves money for households and industry and promotes economic growth.[19]

Expanding beyond the CAT scenario, we examine a progressively larger coverage of a cap on emissions designed to make up the remaining reduction in emissions. The three

[19] The energy import substitution effect was corroborated by the Climate Action Team in its economic analysis of these policies.

industries in Group 1 are frequently identified as the core sectors for a GHG cap. Our results for Scenario 3 suggest, however, that these sectors almost certainly should not bear the burden of adjustment to the 2020 targets alone. Indeed, BEAR estimates of their baseline GHG emissions for 2020 are about 173MMT, while hitting the target would require about 90MMT in emission reductions, an implied annual reduction in sectoral intensity of over 3.5% (see Table 4.3). For this reason, the scenario appears infeasible on a sustained intensity reduction basis, resulting in slightly lower annual real GSP growth and employment statewide.

Table 4.2: Macroeconomic Impacts

Scenario	2	3	4	5	6	7
	CAT	Group1	Group12	Group123	G123Gr	AllIn
Total GHG*	-13	-28	-28	-28	-28	-28
Household GHG*	-32	-32	-32	-32	-31	-30
Industry GHG*	-3	-26	-26	-26	-26	-27
Annual GSP Growth*	2.4	2.4	2.4	2.4	3.1	4.7
Employment*	.10	.06	.08	.08	.44	1.07
Jobs (thousands)	20	13	16	17	89	219
Percent of GHG Target	47	101	100	100	100	100

*Percent change from Baseline scenario in the year 2020.

When the scope of industry coverage is expanded to include the nine industries in Group 2, Scenario 4, the results are much more encouraging. In this scenario, the nine sector group could meet the governor's 2020 targets with less than 3% annual improvements in average emission intensity.[20] While this seems a feasible aggregate objective, however, it is important to recognize that the adjustment burden will fall differently on different sectors, depending on their initial intensity and share of the mitigation they must achieve. One of the advantages of detailed simulation models like BEAR is that they capture these important compositional effects, and in Table 4.3 we see how increasing scope diffuses the burden of adjustment.

In this scenario, the nine sectors responsible for meeting the target will have to reduce emission intensity by up to 3.65% per annum, sustaining this over a nine year period. This level, too, will be difficult to sustain. Even when scope is extended to all industries, Scenario 5, nine year average annual efficiency gains of over 2.9% would be needed.

[20] Note in Table 4.3 that several sectors have much higher annual intensity reductions, some over 4.5%, because of legacy effects from being targeted by CAT policies.

`

The main alternative to this would be extending regulation to services and mobile sources or to orchestrate the present scenario with other GHG policies, yet the all-inclusive Scenario 7 indicates this would still require more than 2% annual mitigation and the administrative feasibility of such a program is very doubtful.

The results in Scenarios 5-7 results are broadly consistent with what is assumed in some other policy analyses. For example, the President's climate change policy for voluntary GHG emission intensity reductions stipulates 2% mitigation per year for ten years (Abraham, 2004), and this goal is approximately in line with historical national trends. California itself has experienced approximately a 2% decline in GHG intensity from 1990-2000 (Climate Action Team, 2006). It must be recalled, however, that these scenarios include some mandatory (direct regulation) CAT policies. The clear message is that California must take policy initiative to achieve these overall levels of abatement.

From Scenarios 2 - 5, we can draw a few salient inferences. Firstly, industry-oriented GHG mitigation needs to be relatively inclusive if the adjustment burden is to be manageable. Second, this category of policy needs to be coordinated with other substantial commitments to GHG efficiency (e.g. CAT regulatory policies). In the case considered here, where an inclusive industry policy is combined with other GHG regulatory initiatives, we find that industry must still improve energy efficiency and GHG gas intensity substantially. Although the implied rates of improvement are probably feasible, they appear to be significantly outside the range of voluntary compliance. The apparent need for more determined and directed mitigation schemes brings us to Scenarios 6 and 7.

`

Table 4.3: Annual Sectoral Emission Intensity

(percent change from Baseline in 2020

Scenario	2	3	4	5	6	7
Sector	CAT	Group1	Group12	Group123	G123Gr	AllIn
A01Agric	.00	-.01	-3.64	-2.95	-2.94	-2.36
A02Cattle	.00	-.01	-.01	-2.95	-2.95	-2.37
A03Dairy	-.47	-.48	-.48	-3.16	-3.15	-2.60
A04Forest	.00	-.01	-.01	-2.95	-2.93	-2.27
A05OilGas	.00	-.03	-.01	-2.96	-2.93	-2.30
A06OthPrim	.00	-.01	-.01	-2.96	-2.90	-2.50
A07DistElec	.00	-4.40	-3.61	-2.93	-2.97	-2.42
A08DistGas	.00	-.01	.00	-2.95	-3.00	-2.52
A09DistOth	.00	-.01	-.01	-2.96	-2.89	-2.21
A10ConRes	.00	-.01	.00	-2.95	-2.85	-2.28
A11ConNRes	.00	.00	.00	-2.95	-2.87	-2.24
A12Constr	.00	-.01	-3.65	-2.96	-2.86	-2.35
A13FoodPrc	.00	-.01	.00	-2.96	-3.00	-2.54
A14TxtAprl	.00	-.01	.00	-2.95	-2.90	-2.48
A15WoodPlp	.00	-.01	-3.65	-2.96	-2.85	-2.17
A16PapPrnt	.00	-.01	.00	-2.95	-2.93	-2.44
A17OilRef	.00	-4.35	-3.58	-2.90	-2.92	-2.34
A18Chemicl	.00	-.01	-3.65	-2.95	-2.91	-2.30
A19Pharma	.00	-.01	.00	-2.95	-2.95	-2.41
A20Cement	-.35	-4.54	-3.78	-3.13	-3.09	-2.60
A21Metal	.00	-.01	-3.65	-2.96	-2.80	-2.08
A22Aluminm	.00	-.01	-3.65	-2.96	-2.82	-2.16
A23Machnry	.00	-.01	.00	-2.95	-2.90	-2.48
A24AirCon	-4.74	-4.74	-4.74	-5.65	-5.62	-5.45
A25SemiCon	-4.44	-4.45	-4.45	-5.47	-5.45	-5.29
A26ElecApp	.00	.00	.00	-2.95	-2.98	-2.82
A27Autos	.00	.00	.00	-2.95	-2.99	-2.73
A28OthVeh	.00	-.01	.00	-2.95	-2.87	-2.32
A29AeroMfg	.00	.00	.00	-2.95	-2.95	-2.70
A30OthInd	.00	-.01	.00	-2.95	-2.87	-2.32
A31WhlTrad	.00	-.01	.00	.00	.25	-2.16
A32RetVeh	.00	-.01	.00	.00	.22	-2.16
A33AirTrns	.00	-.01	.00	.00	.21	-2.21
A34GndTrns	.00	-.01	-.01	-.01	.29	-1.89
A35WatTrns	.00	-.01	-.01	.00	.17	-2.37
A36TrkTrns	.00	-.01	-.01	-.01	.26	-2.27
A37PubTrns	.00	-.01	.00	.00	.20	-2.29
A38RetAppl	.00	-.01	.00	.00	.19	-2.18
A39RetGen	.00	.00	.00	.00	.15	-2.25
A40InfCom	.00	-.01	.00	.00	.17	-2.33
A41FinServ	.00	-.01	.00	.00	.15	-2.42
A42OthProf	.00	-.01	.00	.00	.19	-2.38
A43BusServ	.00	-.01	.00	.00	.21	-2.19
A44WstServ	.00	-.01	-.01	-.01	.23	-2.20
A45LandFill	-1.42	-1.43	-1.43	-3.68	-3.65	-3.10
A46Educatn	.00	.00	.00	.00	.19	-2.09
A47Medicin	.00	.00	.00	.00	.14	-2.36
A48Recratn	.00	-.01	.00	.00	.20	-2.09
A49HotRest	.00	-.01	.00	.00	.24	-2.19
A50OthPrSv	.00	-.01	.00	.00	.21	-2.18
Statewide	-.33	-2.52	-2.52	-2.52	-2.48	-2.52

`

In Scenarios 6 and 7, revenue recycling enables firms to invest in more emission-efficient capital. This not only protects their own balance sheets, but reduces the long term burden of GHG constraints on the California state economy. This mechanism will work most effectively when the innovation potential of investment promotion policies is recognized explicitly. The reinvestment of net revenues from the allocation and transfer of emission allowances is an insurance policy, hedging against adjustment costs, but it can also be a source of growth and technological change.

In Scenario 6, rates of abatement for aggregate and industrial GHG are comparable, while pollution outside the control group rises slightly with growth. The most arresting feature of Table 4.2 is of course the aggregate GSP and job growth resulting from Scenario 7, the all-inclusive mitigation and investment promotion scheme. In this case, by 2020 the California economy would meet the state target of 1990 GHG emissions, while growing 2.5% above the CAT benefits in real terms and creating nearly 200,000 new jobs.[21] The basic reason is very simple: Technology has always made a difference for California and it can make a difference here. What is needed is the right combination of guidance toward state priorities and incentives for private investment, sustained profitability, and productivity growth.

Among other aspects of the aggregate results, the all-inclusive Scenario 7 is the most hypothetical but also suggestive. This experiment assumes it is possible to extend design and implementation of GHG Emissions Targets to all economic activities, including services like transport, ICT, and the public sector. Quite apart from the scientific questions this raises, economywide GHG policy coordination would make the adjustment burden for industry more manageable (only about 2.5% annual intensity reduction), and lead to much greater job creation. This is because the lower efficiency hurdle reduces the concentration of new investment and allows more job intensive expansion of the state economy. Although the all-inclusive scenario represents the biggest administrative challenge, it also mirrors California's last generation of dynamic economic growth, post-industrial expansion favoring service sector employment and incomes.

4.6. Summary

This report evaluates economic implications of California's 2020 greenhouse gas emission reduction target. As is always the case with such forecasting exercises, simplifying

[21] Cumulative income and employment growth over the ensuing nine years would of course be much higher.

`

assumptions are needed to make the analysis tractable. Significantly, a number of these have the effect of making the findings conservative in the sense under-estimating adjustment costs.

- The present analysis does not allow for the substitution of lower GHG content fuels as a means of meeting the 2020 target. The universe of renewable energy generation technologies is large, growing, and increasingly offers cost effective alternatives. Thus the State has a larger set of mitigation options than those modeled here. Forcing all the necessary GHG reductions from a reduced set of options overstates the implied cost of meeting the target.

- The modeling framework does not capture many important and commonplace benefits of technological innovation. The model does incorporate some innovation, and greater capital accumulation (due to lower energy bills) and the resulting increase in productivity drives some important results. However, the technological choice set is very restrictive in the present analysis, allowing only limited factor substitution to achieve emission reductions. Is more reasonable to assume that new technologies available in the coming years will make it easier (less costly) to meet future emission targets.

- Because of time and data limitations, the analysis achieves the cap with no reduction in greenhouse gas emissions from transportation, beyond those embodied in the currently promulgated regulations (Pavley/AB 1493).[22] Since transportation is the single largest source of GHG emissions among all sectors of the economy, and given that numerous significant emissions reduction opportunities have been identified within transportation, we have further reason to believe that the industrial reductions modeled here go further than will be necessary. Put differently, the availability of emissions reductions from mobile-sources will reduce the adjustment burden on stationary sources modeled herein to reduce emissions.

- Exclusion of linkages (offsets). It could be that a Emissions Cap system allows for the purchase of offsets from sources within California or from sources outside the state. These omitted considerations could further lower costs of in-state industry compliance.

Though the foregoing considerations imply a lower cost of meeting the 2020 emission target, it should be noted that the analysis also assumes efficient policy

[22] This is one of the eight specific policies originally modelled in Roland-Holst (2006) and also included in the present analysis as has been explained.

`

implementation. To the extent that actual implementation is less so, costs of attaining the target would probably rise. Public policy efficiency in both design and implementation are thus essential to maximize benefits for the good of the people of California.

5. CONCLUSIONS AND EXTENSIONS

This report summarizes empirical research on economic growth strategies for achieving California's greenhouse gas emission goals. Simply put, emission reductions can achieved in four ways, by reducing the GHG content of inputs by introducing new technologies (e.g. using renewable energy), changing the composition of currently available inputs, reducing output, or improving energy efficiency. This analysis evaluates only the latter three possibilities, and many potential new technologies are not considered.[23] Throughout its modern history and in all its leading economic policies, California has chosen the path of investing in physical and human capital for more productive resource use. The result is one of the world's most prosperous, dynamic, and resilient economies, and one whose potential for innovation is unrivalled. Contrary to a defensive view of those who would defer or even deny the challenge posed by climate change; these results indicate that California can make money its old fashioned way, investing for technological progress to achieving growth and environmental sustainability simultaneously.

Policies to achieve the 2020 emissions target will induce greater investment in energy efficiency, which in turn reduces the level of real resources needed to provide energy-related services needed by the state economy. This, in turn, frees up resources for other uses. In effect, these policies redeploy resources toward more productive patterns of investment and expenditure, benefiting both the economy and the environment. Other investigators studying the effect of policy action to achieve climate change goals report similar findings (Hanson and Laitner 2004; Laitner 2006). Indeed, the State of California's own economic modelers have come to the same conclusion that presented here, that climate policy can generate net benefits in terms of state income and employment (CAT 2006).

These preliminary findings bear out a number of important insights regarding policies toward reducing aggregate emissions from industry. Firstly, all our experiments indicate that, even under favorable incentive and productivity regimes, implied rates of emission

[23] Future work will elaborate the treatment of technology.

`

intensity reduction are outside realistic bounds for voluntary compliance. These results therefore support the state's more determined initiatives to regulate GHG emission, but also strongly suggest that policy effectiveness will depend on respect for market forces and adjustment needs. In this area, it is apparent that coverage of industrial GHG controls should be more inclusive, and extended beyond a handful of first tier emitters to about half the industry groups considered in this study.

These findings also support the now widely held notion that Emissions Cap systems have the potential to deliver economically efficient emission reductions. Despite their attractive valuation and incentive properties, however, Emissions Caps are behaviorally complex and require careful design and monitoring. Our results indicate that they can achieve growth-neutral GHG mitigation more easily if revenues are recycled, but that more growth-positive policies are possible with closer attention to incentives. In particular, one of the most interesting results in this study indicates that combining an Emissions Cap with investment promotion can achieve emission targets with a significant growth dividend. In retrospect for California, this is hardly surprising. The state has been doing precisely this at the margin for two generations, reducing average emission intensity and growing both income and employment.

Going forward, the BEAR model will be expanded to include more microeconomic information. As we have seen here, and is well-known from the literature, firm heterogeneity is an essential determinant of the adjustment process and outcomes arising from emissions policies. This is particularly true with Emissions Cap policies that intentionally enlist market forces to transfer resources within and between diverse industries. The result is induced valuations that reduce public/private cost disparities and improve allocative efficiency. Without detailed within-industry data on firm level efficiency properties, it is difficult to predict the full potential of Emissions Cap and related policies.

In the future, BEAR will also be used to examine more structural and behavioral issues related to Emissions Caps, such as Banking, Borrowing, Safety Valves, and Economic Justice. All these have important implications for economic efficacy and political feasibility, and it is important to improve visibility for policy makers about their potential uses and misuses. Even in the context of the present relatively simple policy simulation experiments, we have seen the emergence of complex interactions and potentially significant behavioral uncertainties. More intensive and extensive empirical research is needed to support effective GHG policies and help California achieve its potential to be the world's leading energy innovation economy.

`

`

6. REFERENCES

Abraham, S. (2004). "The Bush Administration's Approach to Climate Change." Science **305**: 616-617.

Babiker, M.H., J.M. Reilly, M. Mayer, R.S. Eckaus, I. Sue Wing, and R.C. Hyman (2001). "The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results," MIT Global Change Joint Program, Report No. 1, February.

Burtraw, D., Alexander E. Farrell, Lawrence H. Goulder, and Carla Peterman (2006). "Lessons for a Cap and Trade Program," in Hanemann and Farrell (eds.) *Managing Greenhouse Gas Emissions in California, op. cit*.

Burtraw, D. and K. Palmer (2004). The SO2 Cap-and-Trade Program in the United States: A "Living Legend" of Market Effectiveness. Choosing Environmental Policy. W. Harrington, R. D. Morgenstern and T. Sterner. Washington, DC, RFF Press.

California Environmental Protection Agency (2006). "Climate Action Team Report to Governor Schwarzenegger and the Legislature," March, http://www.climatechange.ca.gov/climate_action_team/reports/2006-04-03_FINAL_CAT_REPORT.PDF

Center for Clean Air Policy (2005). Design of a Cap on Emissions from California Power Demand. Washington, DC: 27.

Ellerman, A. D., P. L. Joskow, et al. (2000). Markets for Clean Air: the U.S. Acid Rain Program. Cambridge, UK, Cambridge University Press.

Farrell, A. E. and L. B. Lave (2004). "Emission Trading and Human Health." Annual Review of Public Health 25: 119-138.

Fischer, C. and A. Fox (2004). Output-Based Allocations of Emissions Permits: Efficiency and Distributional Effects in a General Equilibrium Setting with Taxes and Trade. Washington, DC, Resources For the Future.

Fischer, C., I. W. H. Parry, et al. (2003). "Instrument choice for environmental protection when technological innovation is endogenous." Journal of Environmental Economics and Management 45(3): 523-545.

`

Hanemann, W. Michael, and A.E. Farrell (eds.) (2006) "Managing Greenhouse Gas Emissions in California," California Climate Change Center, University of California, Berkeley, January, http://calclimate.berkeley.edu/managing_GHGs_in_CA.html

Hanson, D. and J.A. Laitner (2004). "An integrated analysis of policies that increase investments in advanced-energy efficient/low carbon policies." Energy Economics 26: 739-755.

Harrison, K. and W. Antweiler (2003). "Incentives for pollution abatement: Regulation, regulatory threats, and non-governmental pressures." Journal of Policy Analysis and Management 22(3): 361-382.

Helme, Ned, Tom Peterson, and Eric Williams (2004). "Allowance Allocation: Who wins and loses under a carbon dioxide control program?" Center for Clean Air Policy, http://www.ccap.org/pdf/CRA_Background_Paper.pdf

Hoffert, M., K. Caldeira, et al. (1998). "Energy Implications of future stabilization of atmospheric CO2 content." Nature 395(6075): 881-884.

J.A. Laitner (2006). "An Annotated Review of 30 Studies Describing the Macroeconomic Impacts of State-Level Scenarios Which Promote Energy Efficiency and Renewable Energy Technology Investments." American Council for an Energy Efficiency Economy: Comment Draft (July).

Kartha, S., M. Lazarus, et al. (2004). "Baseline recommendations for greenhouse gas mitigation projects in the electric power sector." Energy Policy 32(4): 545-566.

Kerr, S. and R. G. Newell (2003). "Policy-induced technology adoption: Evidence from the US lead phase down." Journal of Industrial Economics 51(3): 317-343.

Milliman, S. R. and R. Prince (1989). "Firm Incentives to Promote Technological-Change in Pollution-Control." Journal of Environmental Economics and Management 17(3): 247-265.

Montero, J. P. (1999). "Voluntary compliance with market-based environmental policy: Evidence from the US Acid Rain Program." Journal of Political Economy 107(5): 998-1033.

Norberg-Bohm, V. (1999). "Stimulating 'green' technological innovation: An analysis of alternative policy mechanisms." Policy Sciences 32(1): 13-38.

Nordhaus, R. R. and K. W. Danish (2003). Designing a mandatory greenhouse gas reduction program for the U.S. Arlington, VA, Pew Center on Global Climate Change: 66.

`

Ono, T. (2002). "The effects of emission permits on growth and the environment." Environmental & Resource Economics 21(1): 75-87.

Palmer, K., D. Burtraw, et al. (2005). In Search of Simple Rules for Using CO2 Allowances to Compensate Firms. Washington, DC, Resources For the Future.

Pew Center on Global Climate Change(2006). "Designing a Mandatory Greenhouse Gas Reduction Program for the U.S." http://www.pewclimate.org/global-warming-in-depth/all_reports/mandatory_ghg_reduction_prgm/usgas_conc.cfm

Popp, D. (2003). "Pollution control innovations and the Clean Air Act of 1990." Journal of Policy Analysis and Management 22(4): 641-660.

Roland-Holst, David (2006). "Economic Assessment of some California Greenhouse Gas Control Policies: Applications of the Bear Model," in Hanemann and Farrell (eds.) *Managing Greenhouse Gas Emissions in California , op. cit*.

Roland-Holst, David (2005). "Berkeley Energy and Resources Model: Technical Documentation," Department of Agricultural and Resource Economics, University of California, Berkeley, processed.

Rubin, J. D. (1996). "A model of intertemporal emission trading, banking, and borrowing." Journal of Environmental Economics and Management 31(3): 269-286.

Schennach, S. M. (2000). "The economics of pollution permit banking in the context of Title IV of the 1990 Clean Air Act Amendments." Journal of Environmental Economics and Management 40(3): 189-210.

Stavins, R. (2003). Experience with Market-Based Environmental Policy Instruments. The Handbook of Environmental Economics. K. Goren-Maler and J. Vincent. Amsterdam, North-Holland/Elsevier Science. 1.

Taylor, M. R., E. S. Rubin, et al. (2003). "Effect of Government Actions on Technological Innovation for SO2 Control." Environmental Science & Technology 37(20): 4527-4534.

Tietenberg, T. (2003). "The tradable-permits approach to protecting the commons: Lessons for climate change." Oxford Review of Economic Policy 19(3): 400-419.

`

7. APPENDIX – DATA RESOURCES FOR BEAR

The results reported in this study were obtained by implementing the BEAR model with two primary datasets, a detailed Social Accounting Matrix (SAM) for California and emissions data derived from state and national sources. The California SAM is completely documented in Berck et al (2004) and we only review its salient characteristics below. It represents the empirical foundation to which we calibrate a recursive dynamic CGE model and forecast interactions between economic events, pollution, and energy use.

7.1. A 2003 SAM for California

The latest complete SAM for California, just estimated for the year 2003, is the result of a two-year project to assemble and reconcile a variety of state and national economic data into a consistent set of tabular accounts.[24] Generally speaking, the SAM provides a closed form, economywide accounting of linkages between activities (and/or commodities), factors, households, domestic institutions (e.g., investment, government), and out of state institutions in a double entry format that is transparent and amenable to multiplier analysis like that popularized by Leontief as well as more sophisticated CGE analyses. The latter include for example studies focusing on the economic impact of policies toward taxation, external trade, and environment.

[24] The new California SAM is fully documented in Berck et al (2004). Here we only summarize its basic characteristics and discuss our own modifications of this information set.

`

Table A1.1: California SAM for 2003 – Structural Characteristics

1.	124 production activities
2.	124 commodities (includes trade and transport margins)
3.	3 factors of production
4.	2 labor categories
5.	Capital
6.	Land
7.	10 Household types, defined by income tax bracket
8.	Enterprises
9.	Federal Government (7 fiscal accounts)
10.	State Government (27 fiscal accounts)
11.	Local Government (11 fiscal accounts)
12.	Consolidated capital account
13.	External Trade Account

`

Table A1.2: Aggregate Accounts for the Prototype California CGE

1. 50 Production Sectors and Commodity Groups

Sectoring Scheme for the BEAR Model

The following sectors are aggregated from a new, 199 sector California SAM

	Label	Description
1	A01Agric	Agriculture
2	A02Cattle	Cattle and Feedlots
3	A03Dairy	Dairy Cattle and Milk Production
4	A04Forest	Forestry, Fishery, Mining, Quarrying
5	A05OilGas	Oil and Gas Extraction
6	A06OthPrim	Other Primary Products
7	A07DistElec	Generation and Distribution of Electricity
8	A08DistGas	Natural Gas Distribution
9	A09DistOth	Water, Sewage, Steam
10	A10ConRes	Residential Construction
11	A11ConNRes	Non-Residential Construction
12	A12Constr	Construction
13	A13FoodPrc	Food Processing
14	A14TxtAprl	Textiles and Apparel
15	A15WoodPlp	Wood, Pulp, and Paper
16	A16PapPrnt	Printing and Publishing
17	A17OilRef	Oil Refining
18	A18Chemicl	Chemicals
19	A19Pharma	Pharmaceutical Manufacturing
20	A20Cement	Cement
21	A21Metal	Metal Manufacture and Fabrication
22	A22Aluminm	Aliminium
23	A23Machnry	General Machinery
24	A24AirCon	Air Conditioning and Refridgeration
25	A25SemiCon	Semi-conductor and Other Computer Manufacturing
26	A26ElecApp	Electrical Appliances
27	A27Autos	Automobiles and Light Trucks
28	A28OthVeh	Vehicle Manufacturing
29	A29AeroMfg	Aeroplane and Aerospace Manufacturing
30	A30OthInd	Other Industry
31	A31WhlTrad	Wholesale Trade
32	A32RetVeh	Retail Vehicle Sales and Service
33	A33AirTrns	Air Transport Services
34	A34GndTrns	Ground Transport Services
35	A35WatTrns	Water Transport Services
36	A36TrkTrns	Truck Transport Services
37	A37PubTrns	Public Transport Services
38	A38RetAppl	Retail Electronics
39	A39RetGen	Retail General Merchandise
40	A40InfCom	Information and Communication Services
41	A41FinServ	Financial Services
42	A42OthProf	Other Professional Services
43	A43BusServ	Business Services
44	A44WstServ	Waste Services
45	A45LandFill	Landfill Services
46	A46Educatn	Educational Services
47	A47Medicin	Medical Services
48	A48Recratn	Recreation Services
49	A49HotRest	Hotel and Restaurant Services
50	A50OthPrSv	Other Private Services

`

B. 2 Labor Categories

    1. Skilled
    2. Unskilled

C. Capital
D. Land
E. Natural Resources
F. 8 Household Groups (by income
    1. HOUS0 (<$0k)
    2. HOUS1 ($0-12k)
    3. HOUS2 ($12-28k)
    4. HOUS4 ($28-40k)
    5. HOUS6 ($40-60k)
    6. HOUS8 ($60-80k)
    7. HOUS9 ($80-200k)
    8. HOUSH ($200+k)
G. Enterprises
H. External Trading Partners
    1. ROUS Rest of United States
    2. ROW Rest of the World

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

It should be noted that the SAM used with BEAR departs in a few substantive respects from the original 2003 California SAM. The two main differences have to do with the structure of production, as reflected in the input-output accounts, and with consumption good aggregation. To specify production technology in the BEAR model, we rely on both activity and commodity accounting, while the original SAM has consolidated activity accounts. We chose to maintain separate activity and commodity accounts to maintain transparency in the technology of emissions and patterns of tax incidence. The difference is non-trivial and considerable additional effort was needed to reconcile use and make tables separately. This also facilitated the second SAM extension, however, where we maintained final demand at the full 119 commodity level of aggregation, rather than adopting six aggregate commodities like the original SAM.