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Cap and Trade Scenarios for California

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This report is part of a series of research studies into alternative energy pathways for the global economy. In addition to disseminating original research findings, these studies are intended to contribute to policy dialogue and public awareness about environment-economy linkages and sustainable growth. All opinions expressed here are those of the authors and should not be attributed to their affiliated or supporting institutions.

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Executive Summary

As part of its broad spectrum of climate action policies, the state of California is considering instituting a market oriented system of tradable pollution rights, often referred to as a Cap and Trade (C&T) scheme. In particular, this approach is being considered to complete greenhouse gas (GHG) mitigation objectives enunciated in California's Global Warming Solutions Act, returning the state to 1990 GHG emission levels by 2020. As indicated in prior research (e.g. Roland-Holst:2007abc), other climate action initiatives are expected to fall short of the state's overall emission target, and a C&T system may be proposed to achieve the necessary residual emission reductions. In this report, we use the Berkeley Energy and Resources (BEAR) model to provide some initial assessments of how C&T strategies can achieve these objectives and their concomitant effects on the California economy.

Generally speaking, our results indicate that, while ambitious, the state's GHG reduction goals are attainable without significant aggregate economic costs, and indeed California can gain from innovation induced by the right policies. Certainly climate action will entail important adjustments for some individual industries, but to the extent

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that these promote innovation and fuel saving, many economic benefits will accrue that partially or completely offset adoption and other costs. Because the C&T policies considered are market oriented, they enable flexible, price directed allocation of pollution rights and decentralization of innovation decisions. Both these characteristics of C&T contribute to more efficient structural transition and adaptation of the economy to public preferences for reduced CO2 emissions.

When C&T programs are considered in the context of innovation potential, these policies can yield substantial economic benefits. Based on California's historic innovation rates, it is reasonable to expect climate action policies and incentive programs to continue and even accelerate California's historical innovation processes. At best, energy efficiency can join ICT, Biotech, and the state's other knowledge-intensives industries to establish global standards for technologies to meet and new generation of demand for energy saving and pollution mitigation. Climate action is a necessary response to new environmental risks, but it also represents an opportunity to establish competitive advantage in one of the world's most dynamic growth industries.

After detailed examination of a range of actual and proposed policies, we find that the aggregate economic benefits of many GHG mitigation policies outweigh their microeconomic costs. Moreover, some of the most prominent policies can stimulate aggregate economic growth by increasing productivity and efficiency, while contributing to the state's GHG mitigation initiatives.

For a package of GHG mitigation policies recommended by the California Climate Action Team (CAT), we summarize general macroeconomic effects and structural linkages that transmit economic impacts across the state economy. A consistent feature of these results is the economic importance of cumulative indirect and linkage effects, which in many cases far outweigh direct effects. Although the majority of the GHG responses and direct (adoption and monitoring) costs are easily identified, economic benefits of these policies extend over long supply and expenditure chains, the cumulative effect of which can only be assessed with methods like the one used here.

Three salient conclusions emerge from the economic analysis:

1. A variety of policies under active consideration could reduce GHG emissions significantly, at negligible or negative net cost to the overall state economy.
2. Policies that achieve higher levels of energy efficiency permit resources to be reallocated within the state economy, reducing external energy dependence and increasing in-state value added and employment.
3. With improved information and appropriate incentives, most of the GHG policies considered can enlist significant private agency at a public cost that is a small fraction of their potential benefit.

These general conclusions are supported by a myriad of more detailed structural adjustments, the elucidation of which can be essential to design and implement effective policies.

Rigorous policy research tools like the BEAR model can shed important light on the detailed economic incidence of energy and climate policies. By revealing detailed interactions between direct and indirect effects across a broad spectrum of stakeholders, simulation methods of this kind can support more effective policy responses to climate change.

1 Introduction

California's response to rising Greenhouse Gas (GHG) emissions has drawn the world's fifth largest economy into an unprecedented policy dialogue that will influence energy and environmental decisions around the world. Within the state, it is widely acknowledged that GHG policies already implemented and under consideration will have far reaching economic consequences, yet the basis for evidence on these effects remains weak. For this reason, state institutions have expressed an urgent interest in strengthening research capacity in this area.

In response to this, research economists are developing assessment tools to support more effective policy design, implementation, and assessment. One of the most advanced examples of this policy research capacity is the Berkeley Energy and Resource (BEAR) model. BEAR is a detailed and dynamic economic simulation model that traces the complex linkage effects across the California economy as these arise from changing policies and external conditions. BEAR has already been used to produce estimates for the California Environmental Protection Agency, and the same agency now wants to extend the scope and depth of these findings. This proposal envisions building out BEAR's capacity to address a larger set of policies, including the most important ones needed to achieve the state's official GHG targets and capacity to evaluate scenarios for market based incentive schemes like carbon trading.

The last round of BEAR analysis was broadly in accord with the state's findings and buttressed the public interest in legislative discussion of Assembly Bill 32. In the next phase of climate action dialogue, more specific policies will be subjected to intensive public and private scrutiny. At this critical moment of policy debate, it is very important that BEAR's capacity be available for rigorous and objective assessment of the leading issues.

Over the last two years, economists at UC Berkeley have conducted independent research to inform public and private dialogue surrounding California climate policy. Among these efforts has been the development and implementation of a statewide economic model, the Berkeley Energy and Resources (BEAR) model, the most detailed and comprehensive forecasting tool of its kind. The BEAR model has been used in numerous instances to promote public awareness and improve visibility for policy makers and private stakeholders.[2] In the legislative process leading to the California Global Warming Solutions Act (SB32), BEAR results figured prominently in public discussion and were quoted in the Governor's Executive Order to carry out the act.

Climate action policies generally, and cap and trade systems in particular, can have complex behavioral properties and far reaching economic effects. Thus it is important that their detailed economic implications be well understood before they are implemented. In this context, scenario analysis can show how to achieve the state's objectives and improve transparency about outcomes. Responsible analysis in this area can increase the likelihood of two essential results: that the California mechanism works effectively and that it achieves the right balance between public and private interest.

To further elucidate the economic effects of climate action, the BEAR model will be used for ex ante assessment of a range of climate policies, evaluating their individual and combined contributions to the state's performance criteria and other economic and social indicators. By repeated scenario analysis across a spectrum of alternative designs, better practices can be identified, as well as special adjustment needs for individual stakeholders. Initial conditions, such as varying allocation/auction rules and cap phase-ins, can be compared across explicit annual time paths. Dynamic policy components, such as sequencing, banking, safety valves, and adjustment paths, also need to be better understood, and BEAR has the intertemporal structure and sectoral detail to do this. Equity effects of policies, such as energy price changes, need to be anticipated, and

[2] See e.g. Roland-Holst (2006ab, 2007a).

explicit distributional information in BEAR captures this. The six primary dimensions of a generic cap and trade program are summarized in Table 1 below.

In a preliminary exercise to complement the CAT scenario analysis in the first component of the proposed research, BEAR will be used to evaluate primary design characteristics of recommendations emerging from the Market Advisory Committee and other institutions contributing to cap and trade discussions over the next seven months.

While researchers who developed and implement the BEAR model do not advocate particular climate policies, their primary objective is to promote evidenced-based dialogue that can make public policies more effective and transparent. California's bold initiative in this area makes it an essential testing ground and precedent for climate policy in other states, nationally, and internationally. Because of its leadership, the state faces a significantly degree of uncertainty about direct and indirect effects of the many possible approaches to its stated goals for emissions reduction. High standards for economic analysis are needed to anticipate the opportunities and adjustment challenges that lie ahead and to design the right policies to meet them.

This report presents estimates from a new model of California that accounts for the economic and environmental effects of energy and GHG oriented policies. At the heart of the BEAR model is a dynamic computable general equilibrium (CGE) framework that elucidates complex economy-environment linkages in California. Because of the high level of institutional detail captured by the model and its database, it can be applied to a broad spectrum of policy scenarios. Because it determines prices and emission levels dynamically and endogenously, BEAR also captures policy interactions that would be lost in partial equilibrium, static, or sector-specific analysis. Indeed, the model was designed to elucidate the detailed market and incentive properties of a new generation of climate action policies, more complex and far reaching than any attempted to date.

Generally speaking, our results indicate that the scope for GHG mitigation in California is considerable, and that ambitious mitigation targets can probably be met without significant adverse effects on aggregate economic growth. On the contrary, we find that well designed GHG reduction policies can be economically expansionary if they are based on appropriate incentives, limit administrative costs, and promote the innovation and adoption behavior that has delivered historical improvements in emission efficiency.

2 Cap and Trade's Contribution to California Climate Policy

As mentioned above, the C&T approach is intended to complement a range of current and future climate action policies in California. Most prominent among the latter group are a suite of policies termed the Climate Action Team (CAT) recommendations, which were proposed by CalEPA in January 2006. Consisting of over 45 separate sectoral, household, and transportation policies, these are listed in Table 2.1 below. In a previous report (Roland-Holst:2007b), these policies were assessed in cooperation with the California Air Resources board (see also ARB:2007).

In this section, we use the BEAR model to evaluate what C&T can contribute to the state's GHG targets, when implemented in concert with the CAT policies. Given that C&T is supposed to complete the state's mitigation to the 2020 target levels, the first task is to calculate how much residual mitigation will be needed over and above that achieved by the CAT policies. This is less straightforward than it might seem, because interactions between the latter may lead to lower or higher levels of mitigation than the simple arithmetic sum of component policy effects. Also, unanticipated economic effects of CAT policies can influence their effectiveness. For example, fuel efficiency may lower household total fuel cost (even at constant prices), leading to more driving and offsetting part of the expected gain from CAT vehicle measures. Because it captures both policy interaction and secondary market interactions (like the rebound effect), the BEAR model can more accurately predict CAT's net effects, and thereby the residual mitigation needed from C&T. Even in experiments with C&T, the CAT emissions remain endogenous, as their effectiveness at the sector level may be altered by direct and indirect additional policy pressure. An example of the former would be to include CAT target sectors in the C&T program, as many probably will be. If the regulations are simply additive, this could complicate their adaptation. If, by contrast, they received permits in recognition of CAT attainment, it could partially or completely offset adjustment costs. In the present exercise, we hold allocation schemes constant, but clearly these are important design considerations for further analysis.

From another perspective, it is important to go beyond environmental assessment and measure the economic effects of both the CAT measures and the C&T program. A recent study in this series (Roland-Holst:2007c) has already done this kind of assessment for CAT, and we now add a more detailed appraisal of alternative C&T complementary policies. Many different policy designs can achieve equal GHG reductions for California, but the state clearly needs to adopt those that have the most attractive economic characteristics. Again, an energy-environment-economy CGE model like BEAR is best suited to providing these answers. Going forward, BEAR will be used to support more detailed analysis of policy mechanisms for ARB's proposals on climate action, but for the present we want to give some general indications of how C&T policies interact with CAT initiatives to affect both emissions and the state economy.

Table 2.1: CAT Scenario - Climate Action Policies Evaluated

Strategy	Agency	Emissions Reductions MMTCO2e 2010	2020	Double Counted 2020	Anualized (2006$ in 2020) Cost	Saved
Vehicle Climate Change Standards	ARB	1	30		1,331	6,643
Diesel Anti-Idling	ARB	0.64	1.46		58	322
Other New Light Duty Vehicle Technologies	ARB	0	5.4		1,569	1,355
HFC Reduction Strategies	ARB	0	8.7		276	201
Transport Refrigeration Units (on and off road)	ARB	0.01	0.02		21	13
Shore Electrification	ARB	0.08	0.55		150	119
Manure Management	ARB	0	1		45	9
PFC Emission Reduction for Semiconductors	ARB	0.53	0.53		27	0
Alternative Fuels: Biodiesel Blends	ARB	0.4	0.8		0	0
Alternative Fuels: Ethanol	ARB	0.62	2.38		3,102	2,233
Heavy-Duty Vehicle Emission Reduction Measures	ARB	0	3.15		136	698
Venting and Leaks in Oil and Gas Systems	ARB	1	1		10	9
Hydrogen Highway	ARB					
Achieve 50% Statewide Recycling Goal	IWMB	3	3		82	0
Landfill Methane Capture	IWMB	0.89	2.66	0.86	61	171
Zero Waste - High Recycling	IWMB	0	3	0.00	180	111
Conservation Forest Management	Forestry	1	2.35		4	0
Forest Conservation	Forestry	0.4	0.4		15	0
Fuels Management/Biomass	Forestry	1.08	3.0	1.80	1,305	1,559
Urban Forestry	Forestry	0.08	0.88	0.69	287	155
Afforestation/Reforestation	Forestry	0.51	1.98		21	0
Water Use Efficiency	DWR	0.17	0.51		90	358
Building Energy Efficiency Standards in Place	CEC	0.71	2.14		255	658
Appliance Efficiency Standards in Place	CEC	0.41	4.48		509	1,489
Fuel-Efficient Replacement Tires & Inflation Progs	CEC	0.05	0.12		1	32
Building Energy Efficiency Standards in Progress	CEC					
Appliance Energy Efficiency Standards in Progress	CEC					
Cement Manufacturing	CEC	1	1		3	8
Municipal Utility EE Programs/DR	CEC	1.3	6.0		1,632	2,147
Municipal Utility Renewable Portfolio Standard	CEC	1.3	6.0		0	0
Municipal Utility Combined Heat and Power	CEC					
Municipal Utility Carbon Policy (no new coal)	CEC	1.3	6.0		216	0
Alternative Fuels: Non-Petroleum Fuels	CEC					
Measures to Improve Transp Energy Efficiency	BTH	1.68	8.7			
Smart Land Use and Intelligent Transportation	BTH	1.04	9.97			
BTH Strategies	BTH2				2,190	2,190
Conservation tillage/cover crops	Food/Ag					
Enteric Fermentation	Food/Ag	1	1		3	0
Green Buildings Initiative	SCSA	0.5	1.8		559	559
Transportation Policy Implementation	SCSA	0	0		--	--
Accelerated RPS to 33% by 2020	CPUC	3.7	8.2	2.66	100	0
California Solar Initiative	CPUC	0.19	0.92		890	322
IOU EE Programs	CPUC	4.52	3.66		987	1,186
IOU Additional EE Programs	CPUC	0	5.60		1,690	1,790
IOU CHP (Self Generation Incentive Program)	CPUC	0.2	0.4		TBD	TBD
SB 1368 Implementation for IOUs	CPUC	0	0		0	0
IOU Electricity Sector Carbon Policy	CPUC	TBD	TBD		TBD	TBD
Total		30.31	138.73	6.00	17,805	24,337

Source: California Air Resources Board

Table 2.2 below summarizes the general design characteristics of C&T programs, using non-technical terminology as much as possible. In the present section, we examine only the first set of design characteristics, program scope or the sectoral coverage of the emission cap. Other design features will be fixed at default settings indicated as <u>underlined</u> in Table 2.2. For program coverage, Table 2.3 groups the 30 sectors in the current BEAR database into three components. Group 1 sectors are generally considered to be the most intensive stationary sources of GHG emissions in the state, and are primary topics of discussion as target sectors for any C&T program. Group 2 sectors are associated with CAT policies, or of significant GHG interest in their own right, and Group 2 sectors comprise the remainder of the state's economic activity.

In a first set of scenarios, we compare a baseline situation with CAT and C&T policies combined, assuming different levels of CAT fulfillment. Because of their regulatory complexity, CAT policies may fulfill 100% of their GHG reduction objectives or some fraction thereof. In each case, the C&T scheme will assume responsibility for the residual between CAT and the state's 2020 targets for GHG reductions needed to return to 1990 emissions levels. For this reason, the C&T induced mitigation, and its accompanying carbon price, will be greater the less the degree to which CAT meets its targets. For illustrative purposes, we consider CAT fulfillment levels of 100%, 75%, and 50%, and we assume the C&T policy covers all emitting sectors (Groups 1, 2, and 3 of Table 2.2).

Table 2.1: Cap and Trade Program Dimensions

1) Scope/Coverage/Recognition
   a) First tier California
   b) First and Second tier California
   c) All California (or unlimited in-state offsets)
   d) All U. S. offsets
   e) Global offsets
2) Allocation
   a) <u>Auction only</u>
   b) Partial auction
   c) Concessional
3) Revenues
   a) <u>Lump sum to households</u>
   b) Rebate for efficiency investments
   c) Rebate for other mitigation programs – to be specified
4) Banking
   a) <u>No banking</u>
   b) Unlimited banking
   c) Variations – depreciation, sliding scale, etc.
5) Safety-valves
   a) <u>Baseline – no uncertainty</u>
   b) Bands modeled with historic volatility
6) Phase-in
   a) <u>Linear to 2020</u>
   b) Alternatives – to be specified

Table 2.2: Alternative Coverage 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

Baseline Scenario

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

CAT Scenario - Climate Action Team Recommendations

Table 2.1 summarizes the Climate Action Team recommendations, as revised and re-estimated by the Air Resources Board (ARB:2007). These have been discussed in detail elsewhere (Roland-Holst:2007c), and we will not repeat the details of this scenario analysis.

2.1 Policy Interaction – CAT and C&T

In this section, we compare macro results for the three scenarios in Table 2.4. These represent a reference case, assuming California meets its 2020 goals for GHG mitigation, but are designed to show how different combinations of policies might achieve this. The aggregate results in Table 2.4 indicate that, even with technological neutrality, the growth cost of GHG reduction in California is negligible. Even in the worst case, when C&T has to achieve 60% of the targeted mitigation, real GSP declines by less than a quarter of one percentage point in the terminal year. Seen another way, this amount is less than the Baseline state growth rate over two consecutive months, i.e. California's economy could achieve its ambitious climate action goals and overtake Baseline growth trends only two months later, even under pessimistic program and technology assumptions.

Moreover, when the CAT policies are fully effective, employment actually grows in the state economy. This result has been a defining characteristic of BEAR findings for some time, and results from expenditure shifting in response to energy efficiency gains. As households and business reduce relative spending on energy, these expenditures are re-directed to other baseline consumption patterns. As the latter are much more employment and in-state activity intensive, the net result of reduced energy dependence is higher in-state employment and income stimulus that almost fully offsets losses from adjustment costs. Of course these are aggregate results, and the composition of real adjustments will be more diverse, i.e. winners and losers will arise during the process of adjusting to more expensive carbon in the economy.

Table 2.4: Aggregate CAT and C&T Results – Percent Change from Baseline Values in 2020

Scenario	2	3	4	5
	CAT	**C&T 20**	**C&T 40**	**C&T 60**
Real GSP	0.00	-0.13	-0.15	-0.21
Personal Income	-0.86	-0.87	-0.92	-1.02
Employment*	0.05	0.03	-0.04	-0.25
Emissions	-22.56	-28.05	-28.02	-28.13
GHG Reduction (%Target)	80	100	100	100
Emission Price	$0	$22	$67	$206

To achieve targeted GHG mitigation, a Cap and Trade mechanism like the one modeled here transfers the needed structural adjustments to private actors through a market mechanism, offering a choice between investing to increase efficiency or purchasing pollution rights. This approach is generally believed to be more efficient than decentralized command and control systems, which have high monitoring costs and create cost distortions by over narrow policy targeting. Of course the ultimate efficiency of any C&T program depends on its many other design characteristics, but the present example highlights an important one – the absolute mitigation target. In Scenarios 2-4, a progressively larger mitigation target is imposed on the C&T system, and it is apparent from the imputed carbon price (Figure 2.1) that there are limiting elements at work in this system.

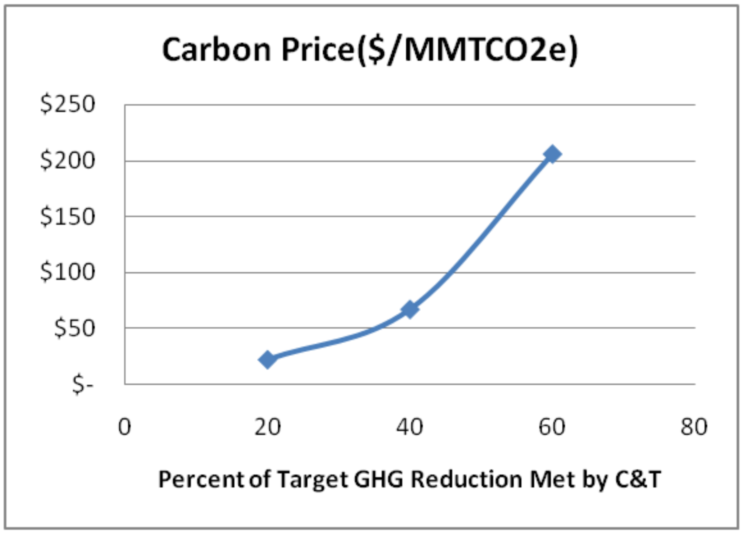
To be precise, the imputed carbon price is the average cost of a pollution permit, denominated in units of Million Metric Tons of CO2 equivalent (MMTCO2e) pollution ("carbon" for short). Clearly this price is nonlinear in relation to the total amount of the GHG mitigation objective, reflecting structural constraints at the sectoral level (i.e. rising marginal costs of abatement). These profiles will differ in the short and long run, becoming more linear and even more horizontal or even decreasing with the advent of efficiency innovations. During the term of the policy, however, it is important to recognize the importance of burden sharing between CAT initiatives and the C&T mechanism. In particular, CAT or C&T exceptions made with reference to the other program will not, generally, improve overall efficiency. In particular, CAT exceptions for targeted sectors will simply transfer the burden to other (C&T) sectors, and may do so in a way that is less efficient. Because they are targeted closer to GHG sources, it is reasonable to infer that CAT policies represent more efficient mitigation. For this reason, our results suggest that CAT policies should be implemented in a way that realizes their fullest mitigation potential, leaving the smallest residual mitigation to be covered by the C&T mechanism.

The scenarios presented here have analogous implications for out-of-state offsets.[3] If CAT policies do not achieve their intended mitigation, California has the option to outsource climate action by recognizing pollution reductions achieved elsewhere. This might rob the state of important long term innovation potential, but of course it could

[3] In-state offsets are discussed in the next scenario set below.

be cheaper in the short term. Carbon prices with 100% CAT fulfillment are in the range observed in overseas carbon markets, but for higher levels this price rises rapidly. In this case, at least on a transitory basis, it might make sense to "infill" offsets for the CAT shortfalls. It is essential for state regulators to recognize, however, that his type of safety valve may undermine necessary long term technology adoption.

Figure 2.1: Imputed Price of Carbon



2.2 Scenarios for Alternative Coverage Schemes

To see the consequences of alternative C&T coverage schemes, we compare three progressive scenarios with C&T imposed on ever more inclusive groups. To be precise, we define a cap on a target population that including Groups 1, 2, and 3, progressively. This cap is computed as the residual between the state's 2020 target and aggregate emissions in the presence of fully effective CAT policies (Scenario 2 above). While it is very difficult to estimate the administrative cost of expanding program coverage, it is useful to see the implications for sectoral induced efficiency levels. Clearly, these induced effects would be greater if CAT policies are less than fully effective.

Results in Table 2.5 indicate that, while coverage may matter to individual sectors, the overall state economy will be little affected by this design choice in macroeconomic terms. Overall state product (real GSP) is imperceptibly affected by coverage, suggesting that the Group 1 and 2 stakeholder groups have little macroeconomic justification for concessions with respect to C&T. On the contrary, the least inclusive system is better for overall state employment, as resources shift to more labor-intensive sectors.[4]

Table 2.4: Aggregate C&T Results – Percent Change from Baseline Values in 2020

	Scenario 6 Group 1, 2, 3	7 Group 1, 2	8 Group1
Real GSP	-0.138	-0.144	-0.158
Personal Income	-0.85	-0.86	-0.88
Employment*	0.05	0.04	0.02
Emissions	-28.08	-28.15	-28.24
Percent of GHG Target	100.00	100.00	100.00
Emission Price	$ 22	$ 58	$ 172

Having said this, adjustments at the sectoral level suggest that choice of coverage will be important for other reasons. The first of these is the actual feasibility of sustained abatement by individual industries. Table 2.6 presents annualized sectoral rates of GHG reduction as these would come from a C&T scheme to hit the state's 2020 target, under three alternative coverage schemes. Sectoral rates will differ according to many factors, including how they participate in emissions trading, indirect linkage effects, and relative adjustment costs. These can vary in the BEAR model because emission levels are endogenous. Three primary forces are at work here:

[4]As previous BEAR results have consistently shown, climate action creates employment at the aggregate level.

1. Policy interaction – In some cases, policies have interactive direct and indirect effects. The former will be deterministic ex ante, and are simply additive. The latter can be quite complex and require detailed inspection to identify positive and negative synergies.
2. Technical substitution – The current scenarios do not take account of the widely perceived potential for climate policies to induce innovation, but BEAR model does allow for technical substitution. In response to price changes, individual sectors a can be expected to substitute fuels, other inputs, and/or factors of productions to achieve greater cost effectiveness.
3. Indirect price effects – Sometimes referred to as rebound effects, these price responses will create a second round of demand adjustments in sectors with significant price changes. In the case of fuels, for example, falling demand may be somewhat offset by induced price declines. Likewise, rising demand for construction services may be partially attenuated by price increases.

Relevant examples of these effects include transport intensive service sectors, like Ground Transport (GndTns) and Wholesale and Retail Trade (WhlTrad). Both sectors experience significant emissions reductions because they are impacted by many components of the CAT policies, yet rising service sector demand offsets any negative output and employment effects for them. This is a combined result of policy interaction and substitution effects, and is typical of the structural transition benefits captured by BEAR. A partial equilibrium analysis of the individual direct industry policy effects would not identify these offsetting gains, yet though they accrue directly to CAT targeted sectors and require no redistribution or compensatory measures and yield a net benefit.

The Cement sector is another prime example, where possible adverse consequences of CAT emissions targeting are more than offset by induced construction demand arising from other CAT policies. These examples highlight the importance of understanding the CAT policies as an integrated package of climate action measures, of seeing both supply and demand side effects, linkages between policy components, and induced market effects. During the implementation process, policy dialogue often decomposed among stakeholder interests, and these integrated economic effects can be overlooked. These results demonstrate the essential contributions policies can make to each other, and the importance of a more comprehensive approach to assessment, design, and implementation.

Returning to Table 2.6, in the most inclusive scheme most industries would have to average 1.35-1.50% annual emission reduction over the period 2012-2020.[5] These rates are commensurate with California's average efficiency gains over the last several decades, and would probably be feasible across the board. When the cap is restricted only to Group 1&2 sectors, average abatement for covered sectors rises to 1.55-2.00% per year, in many cases above historical average rates of improvement. In the most restrictive case, the three Group1 sectors must deliver average abatement rates (above their CAT commitments) of 2.16-2.65% for eight years. These rates are well above the historical average for the state as a whole, and will probably require accelerated depreciation of capital, faster technology adoption, and more rapid induced innovation. All these factors are likely to drive up the price of emissions permits substantially, as the BEAR results in the last row indicate. Technology change in even a few target sectors might be desirable from an innovation perspective, but the potential for technology advancement is probably wider than this, and spillovers for other economic activities will be greater the more diverse is the innovation process. Upon casual inspection then, more inclusive C&T systems have advantages in terms of equity, feasibility, and broader technology externalities.

[5] Note that service sectors are not covered by these schemes, although they may contribute to overall abatement through the CAT policies or indirectly via linkages to covered sectors.

Table 2.6: Sectoral Abatement for Industry (due to C&T alone)
Annualized Percent Reduction in GHG Emissions (2012-2020)

Sector	Scenario 6	Scenario 7	Scenario 8
Agric	-1.46	-1.93	-.02
Cattle	-1.46	-.02	-.02
Dairy	-1.35	-.03	-.02
Forest	-1.42	.05	.10
OilGas	-1.49	-.04	-.05
OthPrim	-1.47	-.01	-.02
DistElec	-1.35	-1.79	-2.52
DistGas	-1.46	-.01	-.01
DistOth	-1.47	-.01	-.01
ConRes	-1.47	-.02	-.02
ConNRes	-1.47	-.02	-.03
Constr	-1.47	-1.96	-.01
FoodPrc	-1.47	-.01	-.01
TxtAprl	-1.47	-.01	-.01
WoodPlp	-1.47	-1.95	.00
PapPrnt	-1.47	-.01	-.01
OilRef	-1.17	-1.55	-2.16
Chemicl	-1.47	-1.96	-.02
Pharma	-1.47	.00	-.01
Cement	-1.41	-1.88	-2.65
Metal	-1.48	-1.97	-.02
Aluminm	-1.48	-1.96	-.02
Machnry	-1.47	-.01	-.01
AirCon	-1.32	-.01	-.01
SemiCon	-1.47	-.01	-.01
ElecApp	-1.45	.02	.03
Autos	-1.45	.01	.01
OthVeh	-1.47	-.01	-.01
AeroMfg	-1.47	-.01	-.01
OthInd	-1.47	-.01	-.01
WhlTrad	-.01	-.01	-.01
RetVeh	-.01	-.01	-.01
AirTrns	-.01	-.01	-.01
GndTrns	-.01	-.01	-.02
WatTrns	-.01	-.01	-.01
TrkTrns	-.01	-.02	-.02
PubTrns	-.01	-.01	-.01
RetAppl	-.01	-.01	-.01
RetGen	.00	.00	-.01
InfCom	.00	.00	-.01
FinServ	.00	-.01	-.01
OthProf	-.01	-.01	-.01
BusServ	.00	-.01	-.01
WstServ	-.01	-.01	-.02
LandFill	-1.37	.00	.00
Educatn	.00	.00	.00
Medicin	.00	.00	.00
Recratn	.00	.00	-.01
HotRest	-.01	-.01	-.01
OthPrSv	-.01	-.01	-.01

For the most inclusive C&T scheme (Scenario 6), more detailed structural adjustments are presented in Table 2.7. Here we see the burden of emissions reduction being shared across all industry sectors, with highest rates among sectors targeted by both CAT and C&T (e.g. Dairy, OilGas, Electric Power, Semiconductors, etc.). Apart from the energy fuel sectors, output effects are difficult to predict from emissions effects. For example, the Construction and Cement sectors both reduce emissions significantly, yet their output and employment rise. These are classic general equilibrium effects, i.e. where aggregate indirect effects reverse direct effects. Because of extensive investment and building demand arising from CAT and accelerated technology change, both these sectors see induced demand growth that more than offsets their individual GHG adjustment costs. Indeed, exactly half of all sectors in the economy see output expand, while emissions levels rise in only seven. Even in this no-innovation scenario, the scope of offsetting growth effects is remarkable.

It is also reasonable to ask about so-called leakage effects, meaning that business activity may be prompted to leave the state because of more stringent environmental regulation. We see no significant evidence of leakage in the BEAR results. On the contrary, here and in the more growth oriented scenarios of the next section, economic expansion caused by climate action and its induced innovation are more likely to make the state a magnet for new economic activities. In our model, it should be emphasized that leakage can only be observed indirectly, as imports from outside the state displacing domestic production. Imports do increase in many sectors in our climate action scenarios, including strategic sectors like construction and cement. Having said this, however, in-state output in each case also increases, suggesting that displacement is not a significant issue. Certainly individual plants and processes may give way to competition from out of state capacity, but at both the aggregate and state level in-state growth does not appear to be crowded out by this. The Aluminum sector is the only case among 50 activities where in-state output decreases (negligibly) and imports rise.

Table 2.7: Scenario 6 - Sectoral Adjustments with Inclusive batement for Industry (due to C&T alone)

Annualized Percent Reduction in GHG Emissions (2012-2020)

Sector	Sector Emissions	Output	Emp	Price	Imports	Exports	Emp
Agric	-12.17	-1.02	-0.90	-.46	-1.93	.18	-.90
Cattle	-12.55	-1.05	-1.68	.82	.58	-.93	-1.68
Dairy	-51.48	-.73	-2.98	.00	-.73	-.16	-2.98
Forest	-8.34	3.18	3.42	-3.86	-.83	4.15	3.42
OilGas	-39.94	-35.96	-33.20	-4.25	-38.71	-5.70	-33.20
OthPrim	-10.97	-11.12	0.28	-3.23	-14.02	.29	.28
DistElec	-42.69	-5.91	-7.11	-6.31	-11.91	.00	-7.11
DistGas	3.76	17.63	17.36	-1.73	.00	5.14	17.36
DistOth	-13.28	-1.54	-2.54	.91	-.63	.00	-2.54
ConRes	-12.13	-.74	-0.84	-.18	-1.10	.00	-.84
ConNRes	15.47	30.74	30.29	-.24	30.11	.00	30.29
Constr	-20.41	22.51	4.85	2.54	28.80	2.24	4.85
FoodPrc	-13.07	-1.34	-2.29	-.59	-3.66	.22	-2.29
TxtAprl	-11.53	-.30	-0.17	-.35	-.65	.24	-.17
WoodPlp	-10.75	.88	0.57	.18	1.07	.03	.57
PapPrnt	-11.63	-.07	-0.50	-.67	-.75	.57	-.50
OilRef	-21.00	-12.23	-10.86	-1.39	-13.46	-1.60	-10.86
Chemicl	-11.89	-.22	-0.87	.03	-.18	-.08	-.87
Pharma	-11.84	-.35	-0.89	-1.01	-1.36	.80	-.89
Cement	-16.38	2.40	1.71	1.05	4.55	-.39	1.71
Metal	-11.63	.25	-0.29	.55	1.36	-.42	-.29
Aluminm	-11.74	-.10	-0.52	3.31	6.62	-2.79	-.52
Machnry	-11.36	.58	-0.12	-.12	.10	.23	-.12
AirCon	-6.18	12.42	5.86	1.97	14.66	.84	5.86
SemiCon	-35.73	-.23	-0.58	-.27	-.50	.18	-.58
ElecApp	-5.02	10.61	7.13	-6.42	3.43	8.22	7.13
Autos	-6.24	5.01	5.80	-6.71	-2.11	7.30	5.80
OthVeh	-10.52	1.75	0.90	.10	1.85	.29	.90
AeroMfg	-11.04	.55	0.30	-.19	.36	.28	.30
OthInd	-11.71	-.26	-0.38	-.26	-.79	.17	-.38
WhlTrad	-26.03	.85	0.59	-.45	-.06	.57	.59
RetVeh	1.43	1.95	1.55	-.58	.77	.92	1.55
AirTrns	-.15	.10	0.04	-.86	-3.32	.77	.04
GndTrns	-43.08	3.16	2.96	-2.97	.07	3.32	2.96
WatTrns	-.07	-1.17	0.02	-1.39	-2.56	.96	.02
TrkTrns	-.04	.44	0.05	-.95	-.52	.92	.05
PubTrns	-.40	.22	-0.14	-1.33	-1.13	1.21	-.14
RetAppl	.30	1.98	0.40	-.15	.00	.55	.40
RetGen	-.17	.37	-0.07	-.73	-.38	.72	-.07
InfCom	.79	1.42	1.06	-.89	-.38	1.08	1.06
FinServ	-2.38	-1.34	-2.12	-1.82	-4.90	1.30	-2.12
OthProf	.34	.91	0.40	-1.06	-1.22	1.13	.40
BusServ	-.48	-.12	-0.27	-.78	-3.20	.65	-.27
WstServ	-1.20	-.63	-0.94	.76	.14	-.79	-.94
LandFill	-69.54	-.86	-5.32	2.02	1.16	-1.90	-5.32
Educatn	2.90	3.44	3.14	-.69	2.72	1.34	3.14
Medicin	-2.08	-1.69	-1.83	-.85	-2.53	.37	-1.83
Recratn	1.42	2.18	1.52	-.66	1.51	1.04	1.52
HotRest	-.01	.68	0.10	-.17	.50	.30	.10
OthPrSv	.70	1.35	0.97	-.34	.67	.58	.97
Total/Average	-29.22	-.59	0.05	-1.15	-.73	1.00	.05

2.3 General Results Interpretation

The general results of the first eight scenarios above are summarized here, with a few additional observations the perspective of current and previous research with the BEAR model.

Aggregate Real Effects on the Economy are Small (Growth is not Threatened)

Despite the environmental and political importance of state's climate policy initiatives, the economic burden of adjustment to the proposed policies is small relative to the California economy. To take two examples, in Scenario 6 the approximate cost of all permits would be less than 2% of the value of output in the target sectors, and a much smaller fraction of state GDP. In a more extreme case, when CAT attains only half its target mitigation and C&T makes up the difference in only three sectors (Scenario 8), the permit cost is much higher (about 24% of three-sector output value), but still less than 2% of state GDP. To the extent that the sectoral costs are passed on, they cannot significantly reduce aggregate state income and consumption. In particular, they are much smaller than most climate damage estimates.

Individual Sector Demand, Output, and Employment can Change Significantly (Economic Structure Changes)

Energy fuel and carbon capped sectors can experience important adjustments, but these are offset by expansion elsewhere, including Services, Construction, and Consumer goods. The California economy is seen undergoing an important structural adjustment, reducing aggregate energy intensity and increasing the labor-intensity of state demand and output. These shifts, masked at the aggregate level, may present opportunities for policy makers to mitigate adjustment costs.

In other words, the aggregate results indicate that the policies considered will pose no significant net cost to the California economy. They might raise costs for some firms and individuals, but as a whole the California economy will probably experience higher growth and create more jobs than it would have without this action (even before considering climate damage aversion). The task for California policymakers in the near term will be to design policies that fairly and efficiently distribute the costs of reducing greenhouse gas emissions.

Combined Effects of the Climate Action Policy Packages have Net Effects On Individual Sectors that Cannot be Identified in Sector-specific Policy Analysis

Because of general equilibrium effects, including policy interaction, technical and expenditure substitution, price (e.g. rebound effects), the effects of individual climate policies on individual sectors can be partially or completely reversed. For this reason, it is essential to assess design and implementation of climate policies in an integrated manner to avoid misleading interpretation of direct effects or disarticulation of the policy dialogue. As a case in point, in the Cement sector, any adverse direct effects of proposed emission regulations are more than offset by new construction demand that is induced by other climate action measures.

Real Output and Employment Effects are Smaller than in Previous BEAR Results

The reason for this is that the first eight scenarios in this report are technology neutral, meaning no autonomous innovation or efficiency improvements are anticipated in response to the C&T measures. By contrast, previous BEAR scenarios assumed induced efficiency gains in line with California's historical trend of ~1.4% per year. This was omitted for comparability with other work by ARB, but in the next section we consider the effects of conservative innovation effects to produce a more credible scenario. As in the past, efficiency gains from induced innovation have been important and consistently observed determinants of the growth dividend from California's energy efficiency policies. In the present context, the positive results would be much larger and the negative results could easily be reversed. This issue is discussed in greater detail below.

Employment Effects are Positive in the Majority of Scenarios

The primary driver of these effects, as in past BEAR estimates, is re-direction of consumer expenditure from energy/fuels to more labor-intensive goods and services. This is one of the most important economic effects of climate action policy, reducing import dependence on capital-intensive fuels and increasing spending on in-state goods and services. The current BEAR scenarios do not allow for migration, so its results are smaller for this reason and because of tech-neutrality.

No Significant Leakage is Observed in the BEAR Scenarios

Import and export adjustments are significant in some sectors, but exhibit no discernable interaction with the carbon constraint in the capped sectors. Imports of fuels fall sharply as the policies dictate, but there is negligible evidence of pollution outsourcing in targeted or energy dependent sectors. In sectors where imports rise, in-state output also rises in every case but one.

No Forgone Damages are Taken into Account

For all scenarios, we have omitted consideration of this important class of policy benefits, including foregone local pollution and attendant public health cost savings. Over a thirteen year time horizon, and considering the amount of pollution reduction, these benefits could be very significant (see e.g. Stern: 2006).

2.4 The Role of Innovation

An important characteristic of the first eight scenarios considered above is sector-specific technological neutrality. This means that factor productivity, energy use intensities, and other innovation characteristics at the individual sector level were held constant across the scenarios, or change only as aggregate averages because of sectoral or factor substitution behavior. Energy use and pollution levels might change, but the prospect of innovation to reduce energy intensity was not considered. This consideration is important for two reasons. Technological change in favor of energy efficiency has been a hallmark of California's economic growth experience over the last four decades. Over this period California has reduced its aggregate energy intensity by about 1.5% per year, attaining levels that today are 40% below the national average. Moreover, most observers credit this technological progress to California's energy/climate policies, combinations of mandated and incentive based efficiency measures from which the Climate Action Team recommendations are direct descendants.

Thus, energy innovation has been part of the history of the state's economic growth and at the same time a consequence of its policies. For these reasons, it is important to consider the potential contribution of continued innovation to the economic effects of California climate policy. For illustrative purposes, we used the BEAR model for two comparison cases to illustrate what innovation could contribute to the economic impact estimates already discussed.

Table 2.8 reports aggregate results for three more scenarios, corresponding to scenarios 6-8 but assuming induced innovation rates of 1.5% per year for sectors covered by the C&T program

The most inclusive case (Scenario 9) corresponds to Scenario 6 and more closely resembles California's past experience with aggregate average improvements. It must be emphasized that even this scenario is conservative by historical standards, however. Only industrial sectors are assumed to improve efficiency, representing about half of all emissions. In addition to services, we omit autonomous efficiency gains by households, as well as spillovers from even the sectors assumed to innovate. Such spillovers are a hallmark of long term energy innovation, so the results below must be seen as conservative.[6]

Table 2.8: Aggregate C&T Results with Autonomous Innovation
Percent Change from Baseline Values in 2020

	Scenario 6 Group 1, 2, 3	7 Group 1, 2	8 Group1
Real GSP	8.98	8.96	8.93
Personal Income	7.67	7.66	7.63
Employment*	6.28	6.27	6.24
Emissions	-27.95	-27.93	-28.89
Percent of GHG Target	80.00	100.00	100.00
Emission Price	$ 8	$ 29	$ 155

If climate action measures are accompanied by continued improvements in efficiency, particularly if this improvement is distributed across many sectors of the economy, it could contribution increase annual real GSP more than 8% by 2020, increase statewide employment by over 6%, and raise real personal incomes by about 4%. If the cap is inclusive, carbon premia will be a modest $8/MT even with accelerated economic growth. All these results are significantly more dynamic than the technology neutral scenarios, but could hardly be called unrealistic. California's innovation potential is one of its most robust economic characteristics.

[6] Some household effects are directly accounted for in the CAT policy scenario that underlies all the counterfactuals.

Sectoral results are displayed in Table 2.9 for the most inclusive scenario. Here we see compositional effects similar to Scenario 6, but uniformly accelerated across the board. Now the only contracting sectors are energy fuels, and output expands robustly in most sectors. In-state production also grows much faster than imports, suggesting that leakage is operating in reverse as California reproduces its own history as a growth magnet driven by innovation.

Although these results are best interpreted as indicative, they have two important implications for the state's climate policy research agenda. Firstly, even the modest assumptions about innovation show it has significant potential to make climate action a dynamic growth experience for the state economy. Second, the size and distribution of potential growth benefits is large enough to justify significant commitments to deeper empirical research on these questions.

If the state is to maintain its leadership as a dynamic and innovation oriented economy, it may be essential for Climate Action for policy to include explicit incentives for competitive innovation, investing in discovery and adoption of new technologies that offer win-win solutions to the challenge posed by climate change for the state's industries and for consumers. In this way, California can sustain its enormous economic potential and establish global leadership in the world's most promising new technology sector, energy efficiency, as it has done so successfully in ICT and biotechnology.

Table 2.9: Scenario 9: Sectoral Adjustments with Historical Innovation Percent Change from Baseline in 2020

Sector	Sector Emissions	Output	Emp	Price	Imports	Exports
Agric	-7.95	9.89	4.95	-7.65	-6.03	9.37
Cattle	-8.16	9.77	1.33	-6.32	-2.60	8.20
Dairy	-49.01	11.16	.07	-7.74	-18.79	9.88
Forest	-3.00	16.27	10.60	-9.27	5.47	12.37
OilGas	-33.22	-19.49	-26.66	-13.93	-35.87	6.86
OthPrim	-8.35	7.47	2.53	-7.35	-5.57	7.26
DistElec	-41.03	4.00	-3.42	-16.18	-12.98	.00
DistGas	4.44	24.22	15.71	-9.66	.00	14.55
DistOth	-7.90	10.39	1.56	-9.10	.25	.00
ConRes	-2.64	12.36	11.01	-5.97	-.66	.00
ConNRes	23.30	41.11	40.59	-5.95	24.81	.00
Constr	-16.02	12.54	11.35	-3.68	22.20	9.61
FoodPrc	-11.52	6.15	-2.47	-8.69	-26.21	9.56
TxtAprl	-9.13	5.77	3.61	-4.23	2.09	5.25
WoodPlp	-3.71	12.16	8.24	-5.50	6.02	7.65
PapPrnt	-7.78	8.54	2.95	-8.80	-1.41	10.13
OilRef	-19.39	-5.00	-8.09	-9.29	-13.91	7.58
Chemicl	-6.60	10.99	3.55	-5.54	6.44	7.79
Pharma	-8.30	10.37	.84	-11.01	-2.91	12.71
Cement	-12.46	10.68	7.59	-5.37	.25	7.46
Metal	-3.51	12.45	10.02	-4.18	6.42	7.10
Aluminm	-4.00	11.10	8.37	-2.83	5.22	4.92
Machnry	-8.68	6.41	2.62	-2.27	8.68	5.93
AirCon	-1.75	12.41	12.03	-.87	24.85	5.90
SemiCon	-31.28	9.54	6.26	-7.14	1.64	8.71
ElecApp	-7.14	8.65	4.07	-9.12	12.03	13.63
Autos	-16.45	-1.45	-4.74	-1.07	-3.41	.42
OthVeh	-6.83	7.51	5.38	-3.54	5.72	5.23
AeroMfg	-4.46	10.14	8.14	-5.07	5.62	7.03
OthInd	-6.53	9.32	6.57	-6.36	-3.50	8.05
WhlTrad	-34.21	11.49	9.41	-8.84	-7.29	10.90
RetVeh	-.25	13.81	9.11	-10.13	-8.06	12.76
AirTrns	-2.63	9.35	7.54	-7.77	-20.87	9.32
GndTrns	-52.68	18.13	15.22	-11.16	5.45	14.94
WatTrns	-4.40	9.26	4.43	-8.24	-.73	9.57
TrkTrns	-3.08	10.62	5.96	-8.50	1.18	10.35
PubTrns	-4.10	11.81	6.70	-11.95	-2.00	14.24
RetAppl	-1.51	12.27	7.80	-10.11	.00	12.34
RetGen	-3.94	9.65	5.06	-10.37	-1.83	12.11
InfCom	-3.38	11.43	7.49	-11.40	-12.70	13.57
FinServ	-8.12	9.33	2.22	-17.94	-26.39	20.91
OthProf	-4.06	10.17	4.52	-11.21	-13.14	13.14
BusServ	-2.75	9.07	7.58	-7.60	-20.51	9.09
WstServ	-3.63	10.78	7.21	-7.79	2.32	9.70
LandFill	-67.62	11.89	-.33	-10.74	-.47	12.95
Educatn	1.22	13.31	12.15	-9.11	3.09	11.61
Medicin	-7.75	3.80	2.63	-8.57	-5.18	8.91
Recratn	-.09	14.34	9.08	-10.40	2.61	13.23
HotRest	-2.44	11.12	6.85	-9.26	.64	11.23
OthPrSv	-2.00	11.68	9.03	-8.11	-5.40	10.25
Total/Average	-27.64	9.39	6.28	-12.29	3.62	9.56

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Annex: 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.[7] 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 activity sectors and ten households aggregated from the original California SAM. The equations of the model are completely documented elsewhere (Roland-Holst: 2005), and for the present we only discuss its salient structural components.

3.1 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

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

prices that correspond to equilibrium in markets and satisfy the accounting identities governing economic behavior. If such a system is precisely specified, equilibrium always exists and such a consistent model can be calibrated to a base period data set. The resulting calibrated general equilibrium model is then used to simulate the 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.[8] The result is a single economy model calibrated over the fifteen-year time path from 2005 to 2020.[9] Using the very detailed accounts of the California SAM, we include the following in the present model:

3.2 Production

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

[9] The present specification is one of the most advanced examples of this empirical method, already applied to over 50 individual countries or combinations thereof.

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.[10] 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.[11] Once the optimal combination of inputs is determined, sectoral output prices are calculated assuming competitive supply conditions in all markets.

3.3 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.[12] The indirect tax schedule will shift to accommodate any changes in the balance between government revenues and government expenditures.

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

[11] 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.

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

Figure 2.1: Component Structure of the Modeling Facility

BEAR is being developed in four areas and implemented over two time horizons.

Components:

1. Core GE model
2. Technology module
3. Emissions Policy Analysis
4. Transportation services/demand

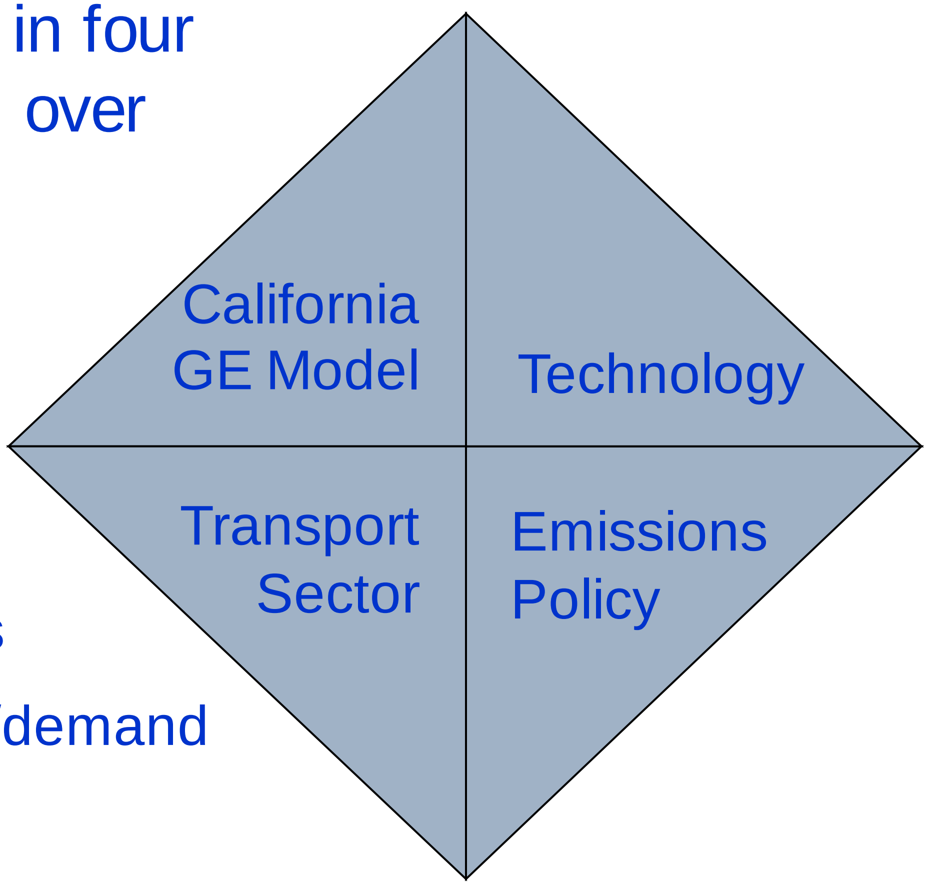
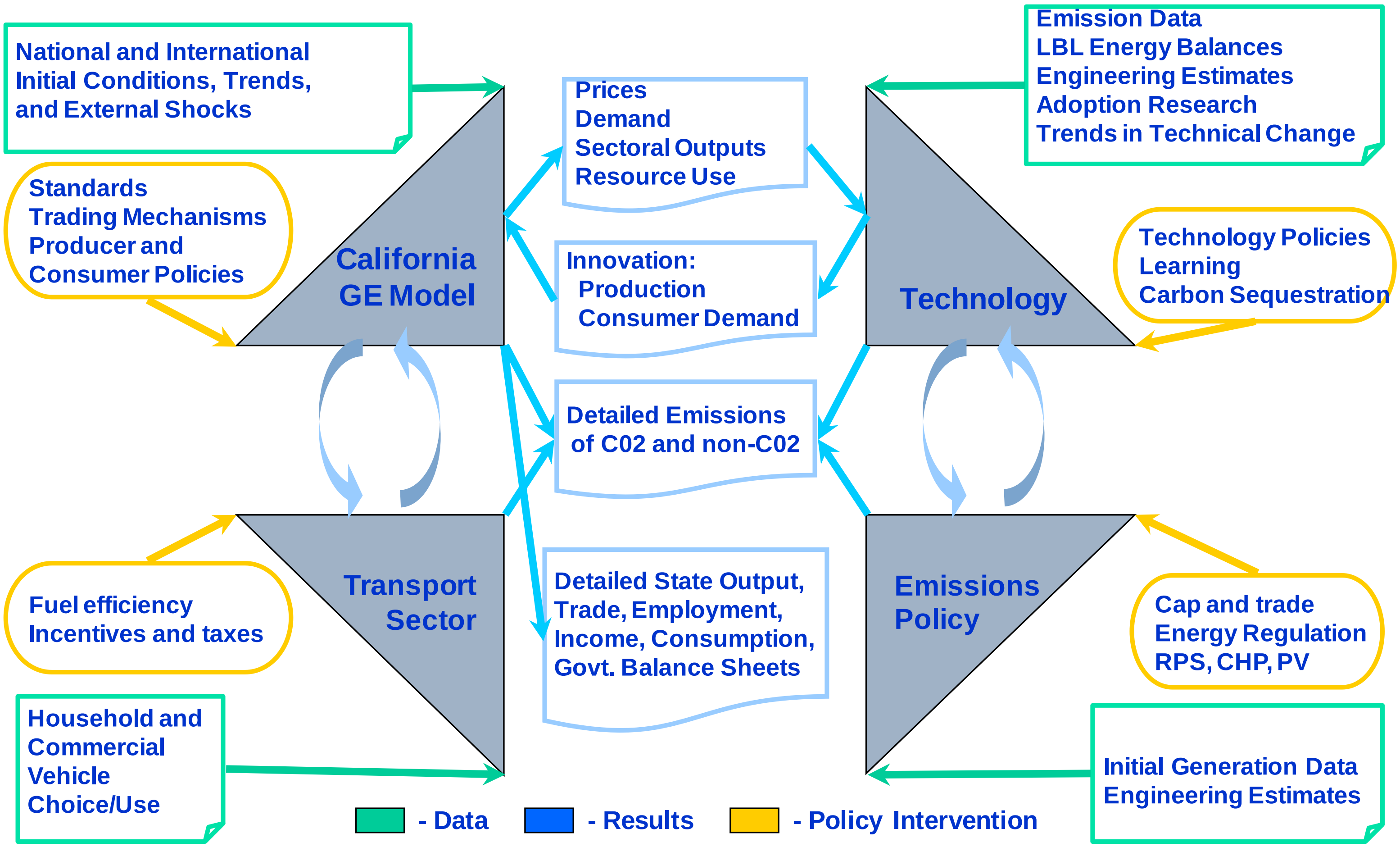


Figure 2.2: Schematic Linkage between Model Components



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

3.4 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.

3.5 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.

3.6 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.

3.7 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.

3.8 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.[13] 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.

3.9 Modeling Emissions

The BEAR model captures emissions from production activities in agriculture, industry, and services, as well as in final demand and use of final goods (e.g. appliances and autos). This is done by calibrating emission functions to each of these activities that vary depending upon the emission intensity of the inputs used for the activity in question. We model both CO2 and the other primary greenhouse gases, which are converted to CO2 equivalent. Following standards set in the research literature, emissions in production are modeled as factors inputs. The base version of the model does not have a full representation of emission reduction or abatement. Emissions abatement occurs by substituting additional labor or capital for emissions when an emissions tax is applied. This is an accepted modeling practice, although in specific instances it may either understate or overstate actual emissions reduction potential.[14] 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

[13]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.
[14] See e.g. Babiker et al (2001) for details on a standard implementation of this approach.

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 A1 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.

An essential characteristic of the BEAR approach to emissions modeling is endogeniety. The BEAR model permits emission rates by sector and input to be exogenous or endogenous, and in either case the level of emissions from the sector in question is endogenous unless a cap is imposed. This feature is essential to capture structural adjustments arising from market based climate policies, as well as the effects of technological change.

Table A1: 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

Table A2: California SAM for 2000 – 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 A3: 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

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.

3.10 Emissions Data

Emissions data at a country and detailed level have rarely been collated. An extensive data set exists for the United States which includes thirteen types of individual and composite emission types (Table A1).[15] The emission data for the United States has been collated for a set of over 400 industrial sectors. In most of the primary pollution databases, measured emissions are directly associated with the volume of output. This has several consequences. First, from a behavioral perspective, the only way to reduce emissions, with a given technology, is to reduce output. This obviously biases results by exaggerating the abatement-growth tradeoff and sends a misleading and unwelcome message to policy makers.

More intrinsically, output based pollution modeling fails to capture the observed pattern of abatement behavior. Generally, firms respond to abatement incentives and penalties in much more complex and sophisticated ways by varying internal conditions of production. These responses include varying the sources, quality, and composition of inputs, choice of technology, etc. The third shortcoming of the output approach is that it give us no guidance about other important pollution sources outside the production process, especially pollution in use of final goods. The most important example of this category is household consumption.

[15] See Martin et. al. (1991).