Economic Evaluation Supplement
Climate Change Draft Scoping Plan Pursuant to AB 32
The California Global Warming Solutions Act of 2006

Appendix III
Economic Analysis of California Climate Policy Initiatives using the Berkeley Energy and Resources (BEAR) Model

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A1. Introduction

For 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.[1] 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.

In this brief contribution, we give an indication of BEAR's policy support capacity with independent assessment of three ARB reference scenarios. Generally speaking, our results support the view that the state can reconcile its goals for economic growth and more sustainable climate policy. The policy choices informed by the scoping process will be more effective, however, if they are supported by rigorous ex ante assessment like that reported here. More evidence-based work of this kind will broaden the basis of stakeholder interest in the state's climate initiative and facilitate constructive policy dialog.

A2. The BEAR MODEL

The Berkeley Energy and Resources (BEAR) model is a constellation of research tools designed to elucidate economy-environment linkages in California. The schematics in Figures 2.1 and 2.2 (below) describe the four generic components of the modeling

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

facility and their interactions. This section provides a brief summary of the formal structure of the BEAR model.[2] 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.

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 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.[3] The result is a single

[2] See Roland-Holst (2005) for a complete model description.
[3] See e.g. Meeraus et al (1992) for GAMS. Berck et al (2004) for discussion of the California SAM.

economy model calibrated over the fifteen-year time path from 2005 to 2020.[4] Using the very detailed accounts of the California SAM, we include the following in the present model:

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.

In each period, the supply of primary factors — capital, land, and labor — is usually predetermined.[5] 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.[6]

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

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.[7] 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

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

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

[6] 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.

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

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.

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.

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.

Figure III.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

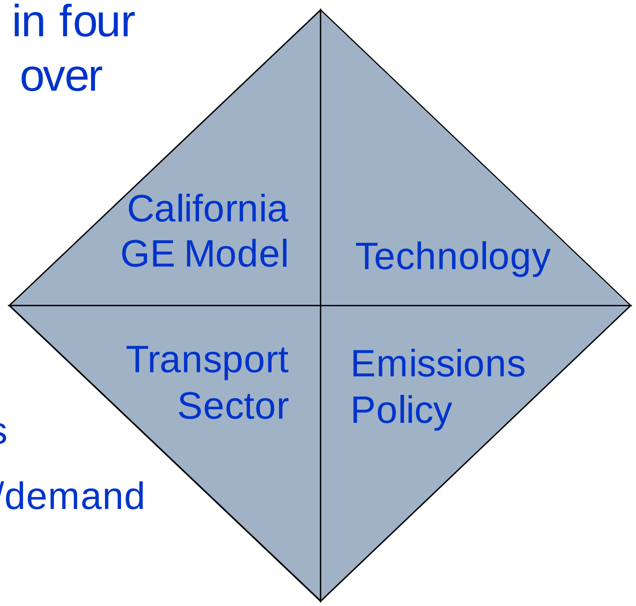
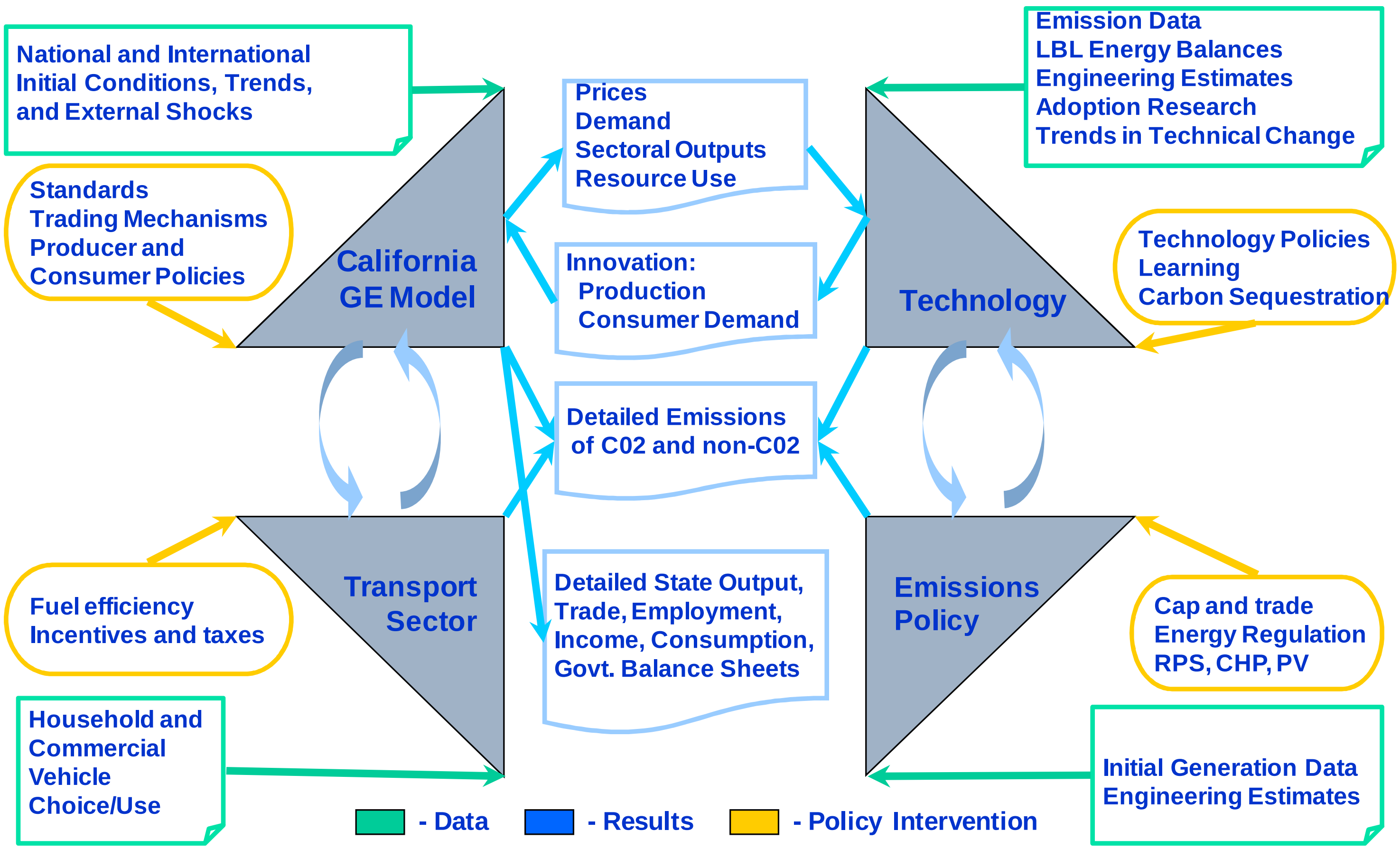


Figure III.2: Schematic Linkage between Model Components



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.

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.

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.[8] 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.

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,

[8] 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.

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

Table III.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
8.	Carbon Dioxide (CO_2)	CO2
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

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

The model has the capacity to track 13 categories of individual pollutants and consolidated emission indexes, each of which is listed in Table III.1. 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 endogeneity. Contrary to assertions made elsewhere (Stavins et al:2007), 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.

A3. BEAR Assessment of the Scoping Plan Scenarios

In this section, we provide a brief summary of the BEAR assessment for ARB climate action scenarios. For the purposes of this attachment, these results are preliminary and represent independent assessment. Analytical approaches, methodological assumptions, data, and evaluation discusses in this attachment represent the opinions of the author and should not be ascribed to the California Air Resources Board or any of their staff.

Scenarios

For the purposes of policy comparison, BEAR was used to evaluate two representative scenarios that take account of Scoping Plan policy recommendations. These scenarios represent the primary policies currently being evaluated for their potential to meet the state's 2020 target of 427 MMTCO2 equivalent overall emissions of greenhouse gases, and are discussed in detail in the main body of the Plan.

The Preliminary Recommendation scenario, in Table III.2, represents the Preliminary Recommendation approach described in the Draft Scoping Plan. This scenario includes the recommended measures that provide the reductions of 169 MMTCO2e in emissions needed to meet the 2020 target.[10] These measures include both a broad-based cap-and-trade program and sector specific measures. In the same table, Sector Specific Measures scenario refers to a scenario that includes the measures other than the cap-and-trade program from the Preliminary Recommendation together with the measures listed as "other measures under evaluation" in the Draft Scoping Plan. Together, these

[10] For full discussion of the Preliminary Recommendation, see the June 26 release of the Draft Scoping Plan.

are envisioned to achieve an estimated 169 MMTCO2e aggregate emission reduction all through developing measures other than the cap-and-trade program that apply to specific economic sectors.

Table III.2: General Scenarios

Number	Label	Description
1	Preliminary Recommendation	Regulations and Standards Recommended in the Scoping Plan, plus Cap and Trade to Attain AB32 Emission Goals for 2020
2	Sector Specific Measures	Sector-specific measures other than the cap-and-trade program included in the Preliminary Recommendation and 'Other Measures Under Evaluation' in the Draft Scoping Plan

Preliminary Recommendation Scenario

E-DRAM results have been discussed in the main body of this document as well as a separate appendix. In this section, we present independent results with general interpretation, offered from the perspective of current and previous research with the BEAR model. In particular, the following tables present aggregate results for the Preliminary Recommendation, including a Baseline or Business as Usual (BAU) that assumes historical trends of energy efficiency. We see here that macroeconomic impacts are relatively (percentage results in Table III.4) limited.

Table III.3: Aggregate Results for Preliminary Recommendation Scenario

Impact Indicator	BAU	Recommended
Real Output ($billion)	3,606	3,640
Gross State Product ($billion)	2,598	2,602
Personal Income ($billion)	2,096	2,092
Per Capita Income (1000s)	48.000	47.479
Employment (Millions)	18.410	18.431
Emissions (MMTCO2e)	596	427
Carbon Price (Dollars)	0	12
Job Growth (thousands)	0	21
Emissions Change (percent)	0	-28
Targeted Reduction (percent)	0	100

This policy package combines significant emissions reduction with in-state economic growth, as measured by real GSP and employment. This result has been a robust characteristic of BEAR and E-DRAM scenarios since the original assessments in support of AB 32 and it is driven by the pro-growth characteristics of energy efficiency and expenditure shifting.[11] Aggregate personal income for the BEAR estimates declines very slightly (less than 2/10 of one percent) in 2020, yet more than 186,000 new jobs are created as the state shifts to more service-intensive economy. The primary reason real GSP differs from real Personal Income is price effects. Real incomes are affected because the policies considered increase the cost of living for most households, but by only a few tenths of one percent, about one tenth of California's average inflation rate over the last two decade. In light of the scope of GHG mitigation achieved, this price effect should be seen as extremely modest. Moreover, this result is consistent with earlier BEAR and E-DRAM work.

Table III.4: Aggregate Variation for Preliminary Recommendation Scenario

(all figures in percent change from the BAU unless otherwise noted)

	Recommended
Real GSP	0.2
Personal Income	-0.2
Employment (Millions)	0.1
Jobs	21
Emissions Change (percent)	-28
Targeted Reduction (percent)	100
Permit Price (Dollars)	12

It is noteworthy that the permit cost for cap and trade component, or implicit endogenous carbon fee arising from the trading system, is relatively low. Permit price estimates are important to the policy debate, since they represent a proxy for adjustment costs. This price is relatively low because, after the Recommended policies, emissions need to be lowered by only an additional (35 out of remaining 462) 7.6% to reach the state's 2020 goal. These results suggest that the private sector can complete the residual mitigation to meet the 2020 goals at relatively modest cost if market mechanisms distribute the adjustment burden across the state's diverse economy.

[11] For a more detailed recent assessment of this issue, see Roland-Holst:2008.

Sector-Specific Measures Scenario

Table III.5 shows the results for the Sector-Specific Measures Scenario. The results of this scenario also show positive impacts on the California economy. Real output and GSP, both increase. Personal income decreases slightly but employment increases as jobs are shifted to service industry and more labor-intensive sectors.

Table III.5: Aggregate Results for Sector-Specific Measures Scenario

Impact Indicator	BAU	Sector-Specific Measures
Real Output	3,606	3,656
Gross State Product	2,598	2,608
Personal Income	2,096	2,093
Per Capita Income (1000s)	48.000	47.503
Employment (Millions)	18.410	18.476
Emissions (MMTCO2e)	596	427
Carbon Price (Dollars)	0	0
Job Growth (thousands)	0	66
Emissions Change (percent)	0	-26
Targeted Reduction (percent)	0	100

Table III.6 shows the percent change from the business-as-usual case. The impacts can be characterized as generally positive. California economy is enormous and the proposed regulations, from an economics point of view, are not only doable, but add stimulus and maintain a sound economy.

The BEAR analysis shows that the state can attain its climate action objectives without sacrificing aggregate economic growth.

Table III.6: Aggregate Variation for Sector-Specific Measures Scenario

(all figures in percent change from BAU unless otherwise noted)

	Sector-Specific Measures
Real GSP	0.4
Personal Income	-0.1
Employment (Millions)	0.4
Jobs	66
Emissions Change (percent)	-26
Targeted Reduction (percent)	93
Permit Price (Dollars)	0

Model Limitations

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. As part of its leadership on climate change the State must assess the direct and indirect economic 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. Progress 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.

The BEAR model's sectoral detail, endogenous emissions, and dynamic innovation and forecasting characteristics enable it to capture a wide range of program characteristics and their role in economic adjustments to climate action. BEAR was designed to model cap and trade systems, and includes all the major design features such as variable auction allocation systems, endogenous permit prices, banking options, safety valves, and fee/rebate systems for CO2 and up to thirteen other criteria pollutants.

All models are necessarily simplifications of reality. While many details of California's economy are omitted from the BEAR assessment framework, however, it does provide reliable guidance regarding the economic impacts that would ensue from climate action measures of the kind considered in the Scoping Plan. The BEAR model has been peer reviewed and represents the most advanced research technologies for economic policy simulation. Still, it is important to understand the uncertainties and limitations that forecasting entails, particularly for complex and unprecedented policy initiatives like the ones considered here. There are three general contexts where the model's results should be interpreted with care.

External shocks: Although it is the world's eighth largest economy, California is and will remain subject to external events beyond its own control. Seismic activity, extreme weather events, and even global energy prices are largely exogenous to the state, yet these will all affect our future. In most cases, however, it can be argued that BEAR results comparing baseline and policy impact will remain applicable. If energy prices were to rise substantially, however, the current estimates of economic benefits from climate action would be lower than actual benefits (compared to the baseline).

Heterogeneity: The main way in which models like BEAR simplify economic reality is by aggregation, examining the behavior of whole sectors of the state economy rather than individual enterprises. Thus a single bank might fail, but the banking sector looks fine on average. Likewise, heterogeneity of technology, decision making, and other firm and plant level characteristics will make climate adaptation a complex and variegated process. BEAR does not predict these individual adjustments, and will thus not capture many adverse and beneficial experiences that make up the aggregate outcomes estimated here. Investing in this kind of detailed insight is more resource intensive, might be desirable for private actors in the economy, but it is not necessarily an efficient use of public resources. Because this type of heterogeneity is at the core of the potential for market mechanisms, such as a cap-and-trade program, to reduce the costs of implementing regulations, BEAR can be expected to underestimate the benefits from market-based compliance mechanisms in implementing AB 32.

Innovation: The overall process of technological change is notoriously difficult to forecast, and individual innovation events virtually impossible. Although we know innovation will be important to California's progress toward a lower carbon future, BEAR does not attempt to predict this component of adjustment endogenously. Having said this, more innovation research would certainly improve guidance for policy makers who want to structure appropriate incentives for technological progress.

The more modest goal of the modeling was to elucidate economic effects of Preliminary Recommendation scenario. In this context, further progress in the policy dialogue will require greater sophistication in both the positive research and its appraisal. In the former category, three areas of improvement should be high priorities for climate change economic modeling:

1. Raw engineering data. There is a tremendous need for increased coverage and greater precision in data on costs, technology profiles, point source emissions across detailed US industrial classifications. It would also be desirable to have more data of this kind in raw form, as opposed to secondary aggregates which may include discount rates and other adjustment factors.
2. More intensive sensitivity analysis and counterfactual experiments. All modeling work in this area needs to evolve from "just-in-time" individual policy analysis to more detached appraisal of structural characteristics. This takes time, but will provide essential insight about future research priorities and policy robustness. This research can help adjudicate disputes about behavioral questions, while also improving the structural features of policy models.
3. Wider policy and research dialogue. Policy making and research processes in the US should continue to widen and improve their internal dialogues, including drawing on insights from European experience and developing country issues, and encouraging greater interaction between the science/technology and economic communities.

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