MIT Joint Program on the Science and Policy of Global Change

Distributional Implications of Alternative U.S. Greenhouse Gas Control Measures

Sebastian Rausch, Gilbert E. Metcalf, John M. Reilly, and Sergey Paltsev

Report No. 185
June 2010

The MIT Joint Program on the Science and Policy of Global Change is an organization for research, independent policy analysis, and public education in global environmental change. It seeks to provide leadership in understanding scientific, economic, and ecological aspects of this difficult issue, and combining them into policy assessments that serve the needs of ongoing national and international discussions. To this end, the Program brings together an interdisciplinary group from two established research centers at MIT: the Center for Global Change Science (CGCS) and the Center for Energy and Environmental Policy Research (CEEPR). These two centers bridge many key areas of the needed intellectual work, and additional essential areas are covered by other MIT departments, by collaboration with the Ecosystems Center of the Marine Biology Laboratory (MBL) at Woods Hole, and by short- and long-term visitors to the Program. The Program involves sponsorship and active participation by industry, government, and non-profit organizations.

To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives. Titles in the Report Series to date are listed on the inside back cover.

Henry D. Jacoby and Ronald G. Prinn,
Program Co-Directors

For more information, please contact the Joint Program Office

Postal Address: Joint Program on the Science and Policy of Global Change
77 Massachusetts Avenue
MIT E19-411
Cambridge MA 02139-4307 (USA)

Location: 400 Main Street, Cambridge
Building E19, Room 411
Massachusetts Institute of Technology

Access: Phone: +1(617) 253-7492
Fax: +1(617) 253-9845
E-mail: globalchange@mit.edu
Web site: http://globalchange.mit.edu/

Printed on recycled paper

Distributional Implications of Alternative U.S. Greenhouse Gas Control Measures[#]

Sebastian Rausch[*‡], Gilbert E. Metcalf[†*], John M. Reilly[*], and Sergey Paltsev[*]

Abstract

We analyze the distributional and efficiency impacts of different allowance allocation schemes for a national cap and trade system using the USREP model, a new recursive dynamic computable general equilibrium model of the U.S. economy. The USREP model tracks nine different income groups and twelve different geographic regions within the United States. Recently proposed legislation include the Waxman-Markey House bill, the similar Kerry-Boxer bill in the Senate that has been replaced by a Kerry-Lieberman draft bill, and the Cantwell-Collins Senate bill that takes a different approach to revenue allocation. We consider allocation schemes motivated by these recent proposals applied to a comprehensive national cap and trade system that limits cumulative greenhouse gas emissions over the control period to 203 billion metric tons. The policy target approximates national goals identified in pending legislation. We find that the allocation schemes in all proposals are progressive over the lower half of the income distribution and proportional in the upper half of the income distribution. Scenarios based on the Cantwell-Collins allocation proposal are less progressive in early years and have lower welfare costs due to smaller redistribution to low income households and consequently lower income-induced increases in energy demand and less savings and investment. Scenarios based on the three other allocation schemes tend to overcompensate some adversely affected income groups and regions in early years but this dissipates over time as the allowance allocation effect becomes weaker. Finally we find that carbon pricing by itself (ignoring the return of carbon revenues through allowance allocations) is proportional to modestly progressive. This striking result follows from the dominance of the sources over uses side impacts of the policy and stands in sharp contrast to previous work that has focused only on the uses side. The main reason is that lower income households derive a large fraction of income from government transfers and, reflecting the reality that these are generally indexed to inflation, we hold the transfers constant in real terms. As a result this source of income is unaffected by carbon pricing, while wage and capital income is affected.

Contents

[#] This paper was written for the Energy Policy Symposium on Distributional Aspects of Energy and Climate Policy held in Washington, D.C., on Jan. 22 -23, 2010, organized by the University of Chicago Energy Initiative, Resources for the Future, and the University of Illinois.

[*] MIT Joint Program on the Science and Policy of Global Change.
[†] Department of Economics, Tufts University, National Bureau of Economic Research.
[‡] Corresponding author: Sebastian Rausch (Email: rausch@mit.edu).

1. INTRODUCTION

U.S. Senate proposals for cap and trade legislation and the House-passed Waxman Markey Bill focus on similar overall cuts in greenhouse gases. The biggest difference among them is how allowances, and the revenue from their auction, would be distributed. Different uses of revenue or different allowance allocations would not in the first instance affect the direct cost of achieving emissions reductions but they can have important implications for how costs are borne by different regions and among households of different income levels. Different uses of revenue may have indirect effects on the overall welfare cost of a policy to the extent revenue is used to offset other distortionary taxes. In addition the allowance allocation has efficiency impacts to the extent that it creates further distortions or prevents pass through of the full CO_2 price in some products, or is used in some way that does not create value for U.S. citizens. Rausch *et al*. (2009) investigated some generic allocation schemes with a multi-region, multi-household static general equilibrium model of the U.S., the U.S. Regional Energy Policy (USREP) model. Here we extend the USREP model to a recursive dynamic formulation and design allocation schemes intended to approximate more closely specific cap and trade proposals.

In extending the USREP model to a recursive dynamic formulation we borrow the dynamic structure of the MIT Emissions Prediction and Policy Analysis (EPPA) model (Paltsev *et al*., 2005). With this extension we are able more closely to represent features of revenue use and allowance allocation in specific legislative proposals and contrast their distributional implications. As with previous analyses of greenhouse gas legislation conducted with the EPPA model such as that in Paltsev *et al*. (2009) we attempt to capture key features of the cap and trade provisions in the proposals but are not able to address many other provisions of the bills that deal with energy efficiency standards and the like. The added value here is that we can consider distributional effects of proposed legislation. We contrast the allowance allocation schemes of the House legislation (Waxman-Markey) with those of the Senate proposals of Kerry and Boxer and of Cantwell and Collins. As a result of negotiations in the Senate the Kerry-Boxer bill has stalled and been replaced by a discussion draft by Senators Kerry and Lieberman. The bill contains a variety of new features but is similar to Waxman-Markey in its allocation of allowance value. To isolate the effects of different allocation schemes, we formulate a cap and trade policy designed to limit cumulative emissions over the control period in all scenarios to 203 billion metric tons (bmt). The cap and trade provisions of the proposals we consider would lead to somewhat different cumulative emissions because of differences in the timing of reductions, sectoral coverage, and whether outside credits were allowed.

Waxman-Markey and Kerry-Boxer are part auction, part free allocation with a complex allowance and revenue allocation designed to achieve many different purposes. In contrast, Cantwell and Collins proposal auctions all allowances and distributes most of the revenue with a very straightforward lump sum allocation to individuals. Extending our analysis to distributional issues requires further interpretation, especially for those proposals with complex allocation schemes, of how allocation of allowances and auction revenue would actually occur if current proposals were implemented.

Our analysis shows a number of results. First, scenarios based on the Waxman-Markey and Kerry-Boxer (or Kerry-Lieberman) allowance allocation schemes are more progressive (i.e., a larger welfare loss is imposed on higher income households) in early years than scenarios based on the Cantwell-Collins proposal. We emphasize, however, that the overall distributional impact of these proposals depend on *all* the proposals contained in these legislative proposals and not just the cap and trade programs. Nonetheless the allowance allocation schemes are important determinants of the overall distributional impact of these bills. Second, scenarios based on the Cantwell-Collins allocation proposal have lower welfare costs due to lower redistribution to low income households and consequent lower income-induced increases in energy demand. Third, we find that the Waxman-Markey and Kerry-Boxer (or Kerry-Lieberman) allocation schemes appear to overcompensate some adversely affected income groups and regions early on though this dissipates over time as the allocation scheme evolves to something closer to lump sum distribution. Fourth, the allocation schemes in all proposals are progressive over the lower half of the income distribution and essentially proportional in the upper half of the income distribution. Finally, we find that carbon pricing by itself, ignoring the return of carbon revenues through allowance allocations, is proportional to modestly progressive. We trace our result to the dominance of the sources side over the uses side impacts of the policy. It stands in sharp contrast to previous work that has focused only on the uses side, and has hence found energy taxation to be regressive. It is worth pointing out that our model framework provides only an analysis of welfare *costs* of climate policy and does not attempt to incorporate any *benefits* from averting climate change. Any welfare changes reported in this paper therefore refer to changes in costs.

The paper is organized as follows: Section 2 briefly describes the recursive dynamic version of the USREP model. Section 3 provides some background on incidence theory. Section 4 discusses the legislative proposals we evaluate, mapping the allowance and revenue allocation in the Bills to specific distributional schemes in the model. Section 5 defines policy scenarios based on the proposed greenhouse gas control measures. Section 6 investigates the distributional implications across regions and income classes of allocation scenarios reflecting our interpretation of proposed policies, and Section 7 reports the results of a counterfactual analysis that allows us to trace the source of distribution effects we observe. Section 8 concludes.

2. A RECURSIVE-DYNAMIC U.S. REGIONAL ENERGY POLICY MODEL

USREP is a computable general equilibrium model of the U.S. economy designed to analyze energy and greenhouse gas policies.[1] It has the capability to assess impacts on regions, sectors and industries, and different household income classes. As in any classical Arrow-Debreu general equilibrium model, our framework combines the behavioral assumption of rational economic agents with the analysis of equilibrium conditions, and represents price-dependent market interactions as well as the origination and spending of income based on microeconomic theory. Profit-maximizing firms produce goods and services using intermediate inputs from other sectors and primary factors of production from households. Utility-maximizing households receive income from government transfers and from the supply of factors of production to firms (labor, capital, land, and resources). Income thus earned is spent on goods and services or is saved. The government collects tax revenue which is spent on consumption and household transfers. USREP is a recursive-dynamic model, and hence savings and investment decisions are based on current period variables.[2]

The USREP model is built on state-level economic data from the IMPLAN dataset (Minnesota IMPLAN Group, 2008) covering all transactions among businesses, households, and government agents for the base year 2006. The detailed representation of existing taxes captures effects of tax-base erosion, and comprises sector- and region-specific *ad valorem* output taxes, payroll taxes and capital income taxes. IMPLAN data has been augmented by incorporating regional tax data from the NBER tax simulator to represent marginal personal income tax rates by region and income class. Energy data from the Energy Information Administration's State Energy Data System (SEDS) are merged with the economic data to provide physical flows of energy for greenhouse gas accounting. Non-CO_2 greenhouse gases are based on the EPA inventory data, and are included as in the EPPA model with endogenous costing of the abatement **(**Hyman *et al.*, 2003).

The basic structure and data used in the USREP model are described in some detail in Rausch *et al*. (2009) with the dynamic structure borrowed from EPPA (Paltsev *et al.*, 2005). We focus discussion here on elements of the model that differ from that described in these two previous papers and on the data sources and calibration needed to

[1] As in any standard computable general equilibrium model, our framework adopts a full-employment assumption and further assumes that money is neutral, i.e. production and consumption decisions are solely determined by relative prices.

[2] Experience from a forward-looking version of the EPPA model (Babiker *et al.,* 2008) suggests that energy sector and CO_2 price behavior are similar to those derived from a recursive-dynamic model. Consumption shifting as an additional avenue of adjustment to the policy may, however, lower overall policy costs. On the other hand, inter-temporal optimization with perfect foresight poorly represents the real economy where agents face high levels of uncertainty that likely lead to higher costs than if they knew the future with certainty. We leave for future work the careful comparison of how alternative approaches to expectations formation may influence model results.

Table 1. USREP Model Details: Regional and Sectoral Breakdown and Primary Input Factors.

Region[a]	**Sectors**	**Primary Input Factors**
Alaska (AK)	**Non-Energy**	Capital
California (CA)	Agriculture (AGR)	Labor
Florida (FL)	Services (SRV)	Land
New York (NY)	Energy-Intensive (EIS)	Crude Oil
New England (NENGL)	Other Industries (OTH)	Shale Oil
South East (SEAST)	Transportation (TRN)	Natural Gas
North East (NEAST)	**Energy**	Coal
South Central (SCENT)	Coal (COL)	Nuclear
Texas (TX)	Convent. Crude Oil (CRU)	Hydro
North Central (NCENT)	Refined Oil (OIL)	Wind
Mountain (MOUNT)	Natural Gas (GAS)	
Pacific (PACIF)	Electric: Fossil (ELE)	
	Electric: Nuclear (NUC)	
	Electric: Hydro (HYD)	
	Advanced Technologies (see Table 3)	

[a]Model regions are aggregations of the following U.S. states: NENGL = Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island; SEAST = Virginia, Kentucky, North Carolina, Tennessee, South Carolina, Georgia, Alabama, Mississippi; NEAST = West Virginia, Delaware, Maryland, Wisconsin, Illinois, Michigan, Indiana, Ohio, Pennsylvania, New Jersey, District of Columbia; SCENT = Oklahoma, Arkansas, Louisiana; NCENT = Missouri, North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa; MOUNT = Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico; PACIF = Oregon, Washington, Hawaii.

regionalize the model. The underlying state level data base provides flexibility in the regional detail of the model. Here we use the regional structure shown in **Figure 1**. This structure separately identifies larger states, allows representation of separate electricity interconnects, and captures some of the diversity among states in use and production of energy. **Table 1** provides an overview of the sectoral breakdown and the primary factors of production. Consistent with the assumption of perfect competition on product and factor markets, production and consumption processes exhibit constant-returns-to-scale and are modeled by nested constant-elasticity-of-substitution (CES) functions. A detailed description of the nesting structure for each production sector and household consumption is provided in Rausch *et al.* (2009).

There are nine representative households in each region differentiated by income levels as shown in **Table 2**. Households across income classes and regions differ in terms of income sources as well as expenditures. State-specific projections through

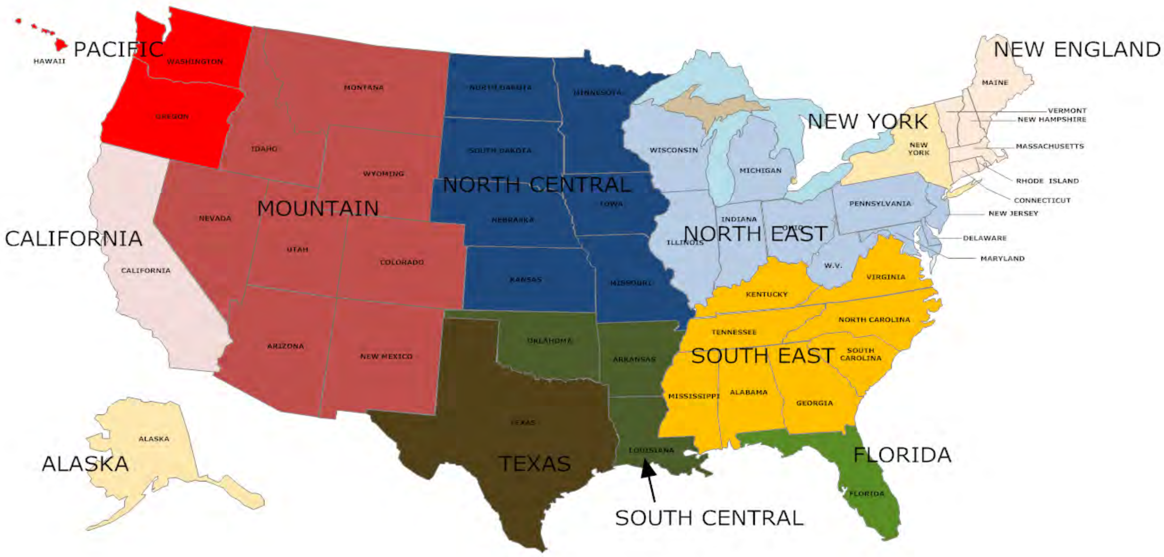

Figure 1. Regional Aggregation in the USREP Model.

2030 are from the U.S. Census Bureau (2009a).[3] Labor supply is determined by the household choice between leisure and labor. We calibrate compensated and uncompensated labor supply elasticities following the approach described in Ballard (2000), and assume for all income groups that the uncompensated (compensated) labor supply elasticity is 0.1 (0.3). Labor is fully mobile across industries in a given region but is immobile across U.S. regions.

Savings enters directly into the utility function which generates the demand for savings and makes the consumption-investment decision endogenous. We follow an approach by Bovenberg, Goulder and Gurney (2005) distinguishing between capital that is used in production of market goods and services and capital used in households (e.g. the housing stock). We assume income from the former is subject to taxation while the imputed income from housing capital is not, and so households can shift investment between market and housing capital in response to changing capital taxation. Lacking specific data on capital ownership, households are assumed to own a pool of U.S. capital—that is they do not disproportionately own capital assets within the region in which they reside.

We adopt the vintage capital structure of the EPPA model. Malleable capital is mobile across U.S. regions and industries, while vintaged capital is region and industry specific. As a result there is a common rate of return on malleable capital across the

[3] The USREP model incorporates demographic data on the population and number of households in each region and income class for the base year 2006 based on U.S. Census Data (2009b). We apply state-specific population growth rates uniformly to all income groups.

Table 2. Income Classes Used in the USREP Model and Cumulative Population.

Income class	Description	Cumulative Population for whole U.S. (in %)[a]
hhl	Less than $10,000	7.3
hh10	$10,000 to $15,000	11.7
hh15	$15,000 to $25,000	21.2
hh25	$25,000 to $30,000	31.0
hh30	$30,000 to $50,000	45.3
hh50	$50,000 to $75,000	65.2
hh75	$75,000 to $100,000	78.7
hh100	$100,000 to $150,000	91.5
hh150	$150,000 plus	100.0

[a]Based on data from U.S. Census Bureau (2009a).

U.S. The accumulation of both malleable and non-malleable capital is calculated as investment net of depreciation according to the standard perpetual inventory assumption. Given base year data about investment demand by sector and by region, we specify for each region an investment sector that produces an aggregate investment good equal to the sum of endogenous savings by different household types. Foreign capital flows are fixed as in the EPPA model. We assume an integrated U.S. market for fossil fuel resources and that the regional ownership of resources is distributed in proportion to capital income. Rausch *et al*. (2009) explored the implications of assuming instead that resource ownership was regional. Such an assumption amplifies regional differences in the impacts of climate legislation, resulting in greater costs for regions with significant energy production but we believe that assumption overestimates regional differences because equity ownership in large energy companies is broadly owned.

Labor-augmenting technical change is a key driver of economic growth as in EPPA. Regional labor productivity growth rates were calibrated to match AEO2009 GDP growth through 2030. Beyond 2030, population and labor productivity growth rates are extrapolated by fitting a logistic function that assumes convergence in growth rates in 2100. The 2100 targets for annual labor productivity growth and for annual population growth are two and zero percent, respectively.

Energy supply is regionalized for USREP by incorporating data on regional fossil fuel reserves from the U.S. Geological Service and the Department of Energy[4]. The resource depletion model and elasticities of substitution between resource and non-resource inputs in fossil fuel production are identical to those in EPPA. As in EPPA, a

[4] Source for crude oil and natural gas reserves: Department of Energy (2009). Source for shale oil reserves: John R. Dyni (2006). Source for coal resources: USGS (2009).

range of advanced technologies not widely present in the base year data are specified in Table 3.

The markups, share parameters and elasticity parameters for the advanced energy supply technologies are those from Paltsev *et al.* (2009) and the same cost mark-ups apply in all regions except for renewables. For renewable the cost shares are taken from

Table 3. Summary of Advanced Technologies in USREP.

Technology	Description
Coal Gasification	Converts coal into a perfect substitute for natural gas.
Shale Oil	Extracts and upgrades shale oil resources into a perfect substitute for oil.
Biomass Liquids	Converts biomass into a perfect substitute for refined oil.
Biomass Electricity	Converts biomass into a perfect substitute for electricity.
Intermittent Wind and Solar	Converts intermittent wind and solar resources into an imperfect substitute for electricity. Costs increase as wind production increases as a share of total electricity production, representing increasing costs of integrating wind into the grid.
Wind with gas backup	Creates a perfect substitute for conventional electricity by jointly building wind turbines and natural gas generation. The gas generation is assumed to operate at a 7% capacity factor—only as a backup when wind is not sufficient to meet load requirements.
Wind with biomass backup	Creates a perfect substitute for conventional electricity by jointly building wind and biomass generation. The biomass generation operates at a 7% capacity factor—only as a backup when wind is not sufficient to meet load requirements.
Advanced Gas	Based on natural gas combined cycle (NGCC) electricity generation technology that converts natural gas into electricity.
Advanced Gas with Carbon Capture and Sequestration	Natural gas combined cycle technology that captures 90% or more of the CO_2 produced in generating electricity.
Advanced Coal with Carbon Capture and Sequestration	Broadly based on an Integrated coal gasification combined cycle (IGCC) plant that captures 90% or more of the CO_2 produced in generating electricity, but can also represent flue gas capture processes.
Advanced nuclear	Next generation of nuclear power plants incorporating estimated costs of building new nuclear power plants in the future.

Paltsev *et al.* (2009) but regional mark-ups and elasticity parameters are derived from regional supply curves. Regional wind supply curves for each technology have been estimated based on high-resolution wind data from NREL (2009) and a levelized cost model described in Morris (2009) that was also the basis for cost estimates in Paltsev *et al*. (2009). The TrueWinds model (NREL, 2009) provides data on the capacity factors for wind turbines if they were located at sites across the U.S., allowing construction of a regional wind supply curve that depends on the quality of wind resources in each region. We derive regional supply curves for biomass from data from Oakridge National Laboratories (2009) that describes quantity and price pairs for biomass supply for each state.

Non-price induced improvements in energy efficiency are represented by an Autonomous Energy Efficiency Improvement (AEEI) parameter as in EPPA, and represent technological progress that reduces at no cost the energy needed in consumption and production activities, thus resulting in reduced energy use per unit of activity and general productivity improvement over time. Reference case energy use is calibrated to the updated AEO2009 reference case (Energy Information Administration (2009)). The baseline thus includes both the impacts of the American Recovery and Reinvestment Act (ARRA) and the Energy Independence and Security Act (EISA).

Sectoral output produced in each region is converted through a constant-elasticity-of-transformation function into goods destined for the regional, national, and international market. All goods are tradable. Depending on the type of commodity, we distinguish three different representations of intra-national regional trade. First, bilateral flows for all non-energy goods are represented as "Armington" goods (Armington (1969)), where like goods from other regions are imperfectly substitutable for domestically produced goods. Second, domestically traded energy goods, except for electricity, are assumed to be homogeneous products, i.e. there is a national pool that demands domestic exports and supplies domestic imports. This assumption reflects the high degree of integration of intra-U.S. markets for natural gas, crude and refined oil, and coal. Third, we differentiate six regional electricity pools that are designed to provide an approximation of the existing structure of independent system operators (ISO) and the three major NERC interconnections in the U.S. More specifically, we distinguish the Western, Texas ERCOT and the Eastern NERC interconnections and in addition identify AK, NENGL, and NY as separate regional pools.[5,6] Within each regional pool, we assume that traded electricity is a homogenous good, where no electricity is traded between regional pools.

Analogously to the export side, we adopt the Armington (1969) assumption of product heterogeneity for imports. A CES function characterizes the trade-off between imported, from national and international sources, and locally produced varieties of the

[5] We identify NY and NENGL as separate pools since electricity flows with contiguous ISOs represent only a small fraction of total electricity generation in those regions. For example, based on own calculation from data provided by ISOs, net electricity trade between ISO New England and ISO New York account for less than 1% of total electricity produced in ISO New England. Interface flows between the New York and neighboring ISOs amount to about 6% of total electricity generation in ISO New York.

[6] The regional electricity pools are thus defined as follows: NENGL, NY, TX, AK each represent a separate pool. The Western NERC interconnection comprises CA, MOUNT, and PACIF. The Eastern NERC interconnection comprises NEAST, SEAST, and FL.

same goods. Foreign closure of the model is determined through a national balance-of-payments (BOP) constraint.

3. BACKGROUND ON DISTRIBUTIONAL ANALYSIS

Carbon pricing through a cap-and-trade system has very similar impacts to broad based energy taxes – not surprising since over eighty percent of greenhouse gas emissions are associated with the combustion of fossil fuels (U.S. Environmental Protection Agency (2009)). The literature on distributional implications across income groups of energy taxes is a long and extensive one and some general conclusions have been reached that help inform the distributional analysis of carbon pricing. First, analyses that rank households by their annual income find that excise taxes in general tend to be regressive (e.g. Pechman (1985) looking at excise taxes in general and Metcalf (1999) looking specifically at a cluster of environmental taxes).

The difficulty with this ranking procedure is that many households in the lowest income groups are not poor in any traditional sense that should raise welfare concerns. This group includes households that are facing transitory negative income shocks or who are making human capital investments that will lead to higher incomes later in life (e.g. graduate students). It also includes many retired households which may have little current income but are able to draw on extensive savings.

That current income may not be a good measure of household well being has long been known and has led to a number of efforts to measure lifetime income. This leads to the second major finding in the literature. Consumption taxes – including taxes on energy – look considerably less regressive when lifetime income measures are used than when annual income measures are used. Studies include Davies, St. Hilaire and Whalley (1984), Poterba (1989, 1991), Bull, Hassett and Metcalf (1994), Lyon and Schwab (1995) and many others.[7]

The lifetime income approach is an important caveat to distributional findings from annual incidence analyses but it relies on strong assumptions about household consumption decisions. In particular it assumes that households base current consumption decisions knowing their full stream of earnings over their lifetime. While it is reasonable to assume that households have some sense of future income, it may be implausible to assume they have complete knowledge or that they necessarily base spending decisions on income that may be received far in the future.[8] It may be that the truth lies somewhere between annual and lifetime income analyses. Moreover, if one

[7] Most of these studies look at a snapshot of taxes in one year relative to some proxy for lifetime income – often current consumption based on the permanent income hypothesis of Friedman (1957). An exception is Fullerton and Rogers (1993) who model the lifetime pattern of tax payments as well as income.

[8] On the other hand casual observation of graduate students in professional schools (business, law, medicine) make clear that many households are taking future income into account in their current consumption decisions.

were to use a lifetime income approach, one would like to track consumption over the lifecycle to capture any lifecycle changes in the consumption of carbon intensive products and compare lifetime carbon pricing burdens rather than a single-year snapshot. This paper takes a current income approach to sorting households.

Turning to climate policy in particular a number of papers have attempted to measure the distributional impacts of carbon pricing across household income groups. Dinan and Rogers (2002) build on Metcalf (1999) to consider how the distribution of allowances from a cap and trade program affects the distributional outcome. Both these papers emphasize that focusing on the distributional burden of carbon pricing (either a tax or auctioned permits) without regard to the use of the revenue raised (or potentially raised) from carbon pricing provides an incomplete distributional analysis. How the proceeds from carbon pricing are distributed have important impacts on the ultimate distributional outcome.

The point that use of carbon revenues matters for distribution is the basis for the distributional and revenue neutral proposal in Metcalf (2007) for a carbon tax swap. It is also the focus of the analysis in Burtraw, Sweeney and Walls (2009). This latter paper considers five different uses of revenue from a cap and trade auction focusing on income distribution as well as regional distribution. A similar focus on income and regional distribution is in Hassett, Mathur and Metcalf (2009). This last paper does not consider the use of revenue but does compare both annual and lifetime income measures as well as a regional analysis using annual income. Grainger and Kolstad (2009) do a similar analysis as that of Hassett, Mathur and Metcalf (2009) and note that the use of household equivalence scales can exacerbate the regressivity of carbon pricing. Finally Burtraw, Walls and Blonz (2009) consider the distributional impacts in an expenditure side analysis where they focus on the allocation of permits to local distribution companies (LDCs). Rausch *et al*. (2009) also investigate the welfare costs of allocations to LDCs and find that allocations that lead to real or perceived reductions in electricity prices by consumers have large efficiency costs.

With the exception of the last paper, all of the papers above assume that the burden of carbon pricing is shifted forward to consumers in the form of higher energy prices and higher prices of energy-intensive consumption goods and services. That carbon pricing is passed forward to consumers follows from the analysis of a number of computable general equilibrium models. Bovenberg and Goulder (2001), for example, find that coal prices rise by over 90 percent of a $25 per ton carbon tax in the short and long run (Table 2.4).[9] This incidence result underlies their finding that only a small percentage of permits need be freely allocated to energy intensive industries to

[9] They assume world pricing for oil and natural gas so that the gross of tax prices for these two fossil fuels rise by the full amount of the tax.

compensate shareholders for any windfall losses from a cap and trade program. See also Bovenberg, Goulder and Gurney (2005) for more on this issue.

Metcalf *et al.* (2008) consider the degree of forward shifting, as a result of higher consumer prices and backward shifting, as a result of lower factor returns, over different time periods for a carbon tax policy begun in 2012 and slowly ramped up through 2050. The tax on carbon emissions from coal are largely passed forward to consumers in all years of the policy in roughly the same magnitude found by Bovenberg and Goulder (2001). Roughly ten percent of the burden of carbon pricing on crude oil is shifted back to oil producers initially with the share rising to roughly one-fourth by 2050 as consumers are able to find substitutes for oil in the longer run. Interestingly the consumer burden of the carbon tax on natural gas exceeds the tax. This reflects the sharp rise in demand for natural gas as an initial response to carbon pricing is to substitute gas for coal in electricity generation. By 2050 the producer price is falling for reasonably stringent carbon policies.[10]

Fullerton and Heutel (2007) construct an analytic general equilibrium model to identify the various key parameters and relationships that determine the ultimate burden of a tax on a pollutant.[11] While the model is not sufficiently detailed to provide a realistic assessment of climate change impacts on the U.S. economy it illustrates critical parameters and relationships that drive burden results.

The general equilibrium models discussed above all assume a representative agent in the U.S. thereby limiting their usefulness to considering distributional questions. Metcalf *et al*. (2008) apply results from a representative agent model to data on U.S. households that allows them to draw conclusions about distributional impacts of policies but the household heterogeneity is not built into the model.[12]

Several computable general equilibrium (CGE) models have been constructed to investigate regional implications of climate and energy in the U.S. For example, the ADAGE model, documented in Ross (2008), has a U.S. regional module which is usually aggregated to five or six regions. The MRN-NEEM model described in Tuladhar *et al.* (2009) has nine U.S. regions. Both these models use a single representative household in each region.

---

[10] Distributional results depend importantly on the stringency of policy. How stringent the policy is affects whether carbon free technologies are adopted in the EPPA model and therefore what the relative demand for fossil fuels is. In the text above we are reporting carbon tax results for a policy that limits emissions to 287 billion metric tons over the control period.

[11] The paper also provides a thorough summary of the literature on the incidence impacts of environmental taxes.

[12] A recent paper by Bento *et al.* (2009) marks an advance in the literature by allowing for household heterogeneity over income and location. That paper considers the impact of increased U.S. gasoline taxes taking into account new and used car purchases along with scrappage and changes in driving behavior.

Rausch *et al*. (2009) does an explicit CGE analysis of carbon pricing in a single-period CGE model. That analysis considers a variety of possible allocations of the revenue and/or allowances from cap-and-trade system and finds that the use of revenues affects the overall progressivity of the policy substantially. It also finds that a significant portion of the carbon price is passed back to factors of production – most notably owners of natural resources and capital. This contributes to a greater progressivity of carbon pricing than found in literature that assumes full forward shifting.

4. U.S. CAP AND TRADE PROPOSALS: ALLOWANCE ALLOCATION

Below we carry out distributional analyses of cap and trade policies based on alternative proposals for greenhouse gas control legislation currently under consideration in the U.S. These are the house-passed American Clean Energy and Security Act (H.R. 2454) sponsored by Reps. Waxman and Markey, the Clean Energy Jobs and American Power Act (S. 1733) a Senate bill similar to H.R. 2454 and sponsored by Senators Kerry and Boxer, and now replaced by the American Power Act (APA) draft bill by Kerry and Lieberman, and the Carbon Limits for America's Renewal (CLEAR) Act, a competing Senate Bill sponsored by Senators Cantwell and Collins.

All proposals seek an overall reduction of GHG emissions in the U.S. to 83% below 2005 levels by 2050 with intervening targets. Cap and trade components of the bills cover most of the economy's emissions but not necessarily all of them, with other measures directed toward uncapped sectors. For example, estimates are that Waxman-Markey covers between 85% and 90% of emissions with a cap and trade system. Waxman-Markey has a slightly looser target for sectors covered by the cap and trade in 2020 than does Kerry-Boxer, issuing allowances at a level 17% below 2005 emissions in 2020, whereas the economy-wide goal is a 20% reduction by that date. Kerry-Lieberman would sell as many allowances as needed to refineries at a fixed price but would adjust over time to meet quantity targets. In our simulations of the effects of these bills, we assume the national goals are met, and we achieve them with a cap and trade system that covers all U.S. emissions except for land use CO_2 sources (or sinks). All of these proposals including banking and limited borrowing provisions and hence the time profile of reductions described in the bills are better thought of as the time profile of allowance allocation, with actual emissions levels in each year determined by how allowances are banked or borrowed (to the extent borrowing is allowed). In our simulations we find that the allocations result in net banking with no borrowing. Of course, in actuality borrowing may occur to the extent that unexpected costs make it attractive to bring permits forward in time.

While the stated national targets are identical across the bills, the Cantwell and Collins proposal has no provision for the use of offsets from outside the capped sectors to be used in lieu of the cap. Reductions similar in nature to the offsets allowed in the other bills are to be funded from a portion of the auction revenues that are subject to future appropriations. The other two proposals allow up to two billion tons per year of outside credits from a combination of domestic and foreign sources. In our simulations the domestic credits would need to come from a combination of reduced land use emissions and increased land use sinks. Foreign credits would come from qualified reductions abroad. As shown in Paltsev *et al.* (2009) if these credits are available at reasonable costs they would significantly reduce the CO_2 price and expected welfare cost of the legislation. Emissions from the capped sectors then are reduced much less than the target levels in the bill because available allowances are supplemented with external credits. Our main interest in this paper is the consequences of alternative distribution of allowances, and so we simulate the Cantwell-Collins allocation scheme allowing for the same level of outside credits as the other two bills. Any differences are the result of the allowance distribution mechanisms rather than the level of the cap.

The proposals are not always clear as to whether allowances are auctioned by some central Federal Agency and the revenue distributed or the allowances are distributed to entities who then can sell them. For example, designations to States could involve either a portion of allowance revenue or direct allocation of allowances leaving it up to the State to sell them into the allowance market. For our modeling purposes it does not matter whether it is revenue or the allowances that are distributed. We thus focus in our analysis on the allocation of "allowance value" in the different proposals to allow for distribution of allowances or the revenue from an auction.

Figure 2 shows the allowance allocation scheme as it is proposed in the Waxman-Markey bill. We do not show graphically the Kerry-Lieberman, Kerry-Boxer and Cantwell-Collins allowance allocation schemes here. The Cantwell-Collins bill calls for 75% of allowance revenue to be returned in a lump sum manner and 25% retained to meet several objectives but without specifying percentages for each. In terms of Figure 2, that bill would be simply two bars dividing allowance value among these two purposes. The allocation schemes in Kerry-Boxer and Kerry-Lieberman are similar to Waxman-Markey. The main difference is in terms of allowances set aside to offset the impact of the bill on the deficit. Waxman-Markey allocates at most 10% of the allowances for this purpose, in part directly and in part by directing how revenues obtained through early auction would be used, whereas Kerry-Boxer allocates a percentage that grows to 25%.[13] The allocation of revenue for deficit impacts in Kerry-Lieberman is much closer to Waxman-Markey. The increasing share devoted to this purpose proportional reduces the allocation to all other purposes. For example, Kerry-Boxer is able to allocate less than 50% of allowance value directly to households

[13] This depends in part on whether future vintage allowances are sold early in the 2014-2020 period. If so, the share of allowances allocated to deficit reduction rises to roughly 12 percent of total allowances (current allowances and future allowances brought forward).

through either the low income energy assistance or the consumer rebate fund—whereas Waxman-Markey is able to allocate about 65% to households by 2050 through these two programs.

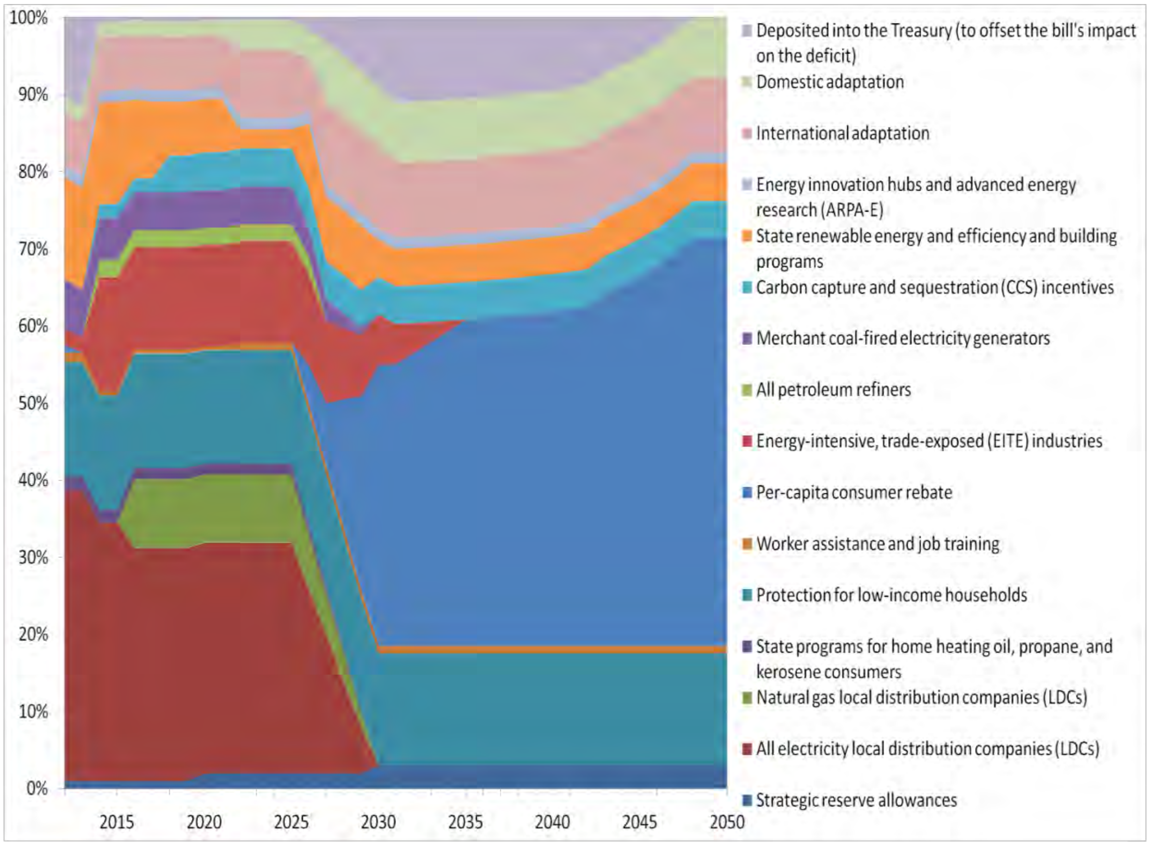

Figure 2. The Allocation of Allowance Value in the Waxman-Markey Bill.

Both Kerry-Boxer and Waxman-Markey have a small strategic reserve of allowances and both allocate a substantial portion of allowances to local electricity and natural gas distribution companies in early years on the basis that these regulated entities will turn allowance value over to ratepayers, thus offsetting some of the impact of higher energy prices. This turns these LDCs into the mechanism for distribution as opposed to a government auction agency as in Cantwell-Collins. The other bills transition to a system closer to Cantwell-Collins over time, replacing the LDC distribution with a consumer rebate fund. Both retain a separate allocation to focus specifically on low income energy consumers. Both also then distribute allowances to different industries that are expected to be particularly affected by the legislation, but these allocations phase out by 2030. Use of allowances as an extra incentive for carbon capture and sequestration is also identified in both. A next set of allowances are allocated to fund various domestic energy efficiency programs. The next grouping of allocations is for international mitigation and adaptation and for domestic adaptation programs.

Waxman-Markey contains a large set of allowances in later years designated for prior year use. This use possibly reallocates allowances through time, allowing the possibility of Federal borrowing if allowance prices rise too much. Of more relevance here is that the bill prescribes about one-half of this allowance value to go to the Treasury to offset impacts on the deficit and the other half as a consumer rebate. These amounts are shown in Figure 2 combined with the other provisions that direct revenue to the Treasury and to the consumer rebate. That value is allocated in the year in which the allowances would be originally issued, i.e. assuming the Federal government does not borrow them or if it does, the income is not rebated immediately. The Kerry-Boxer bill does not have this provision.

We do not represent the many different programs to which these allowances or allowance value would go and the exact recipients will depend on program decisions yet to be made. However, we approximate the impact on regions and households of different income levels by distributing the allowance value based on data we have within the model, and that approximates what we believe to be the intent of the different distributions or how they would tend to work in practice. The distributional instruments we have at our disposal in the USREP Model and the correspondence to allocations called out in the bills are given in **Table 4**. For example, we allocate to households the proposed distribution of allowances to LDCs based on emissions and respective electricity and natural gas consumption. To determine the regional distribution, we allocate 50% of LDCs allowances based on historic sectoral emissions for the electricity and natural gas sector, respectively. The other half is allocated to regions based on household electricity and natural gas consumption.[14] Within a region, allowances to LDCs are allocated based on respective fuel consumption. Allocations designated for low income households are distributed to households with incomes of less than $30,000 per year.

Distributions to industries other than LDCs go to households based on their capital earnings on the basis that this value will be reflected in the equity value of firms, and so households that own capital, for example, through stock ownership, will be the beneficiaries.[15] Allowances distributed for energy efficiency and such are distributed by region based on regional energy consumption and then within a region by energy consumption by household on the basis that regions and households that consume more

[14] Rausch *et al*. (2009) consider the efficiency implications of a misperception by households that this lump-sum transfer lowers the marginal price of electricity and natural gas.

[15] An output-based rebate (OBR) to energy-intensive and trade-exposed (EITE) industries may result in a greater pass-through of allowance value to end consumers relative to our allocation based on capital earnings. How this allowance should be divided up, however, depends on factors such as the degree of pass-through in downstream sectors, given that EITE products are often intermediate goods, e.g. steel. Our approach treats all vulnerable industries symmetrically, and we allocate allowances lump sum proportional to capital income. Our approach does not capture incentive effects that would arise if allowance value was used to subsidize output in these industries. Such output subsidies would incur additional efficiency costs that we do not capture.

energy have more opportunities to take advantage of these programs. Allowances designated for worker assistance are distributed to regions based on oil and coal

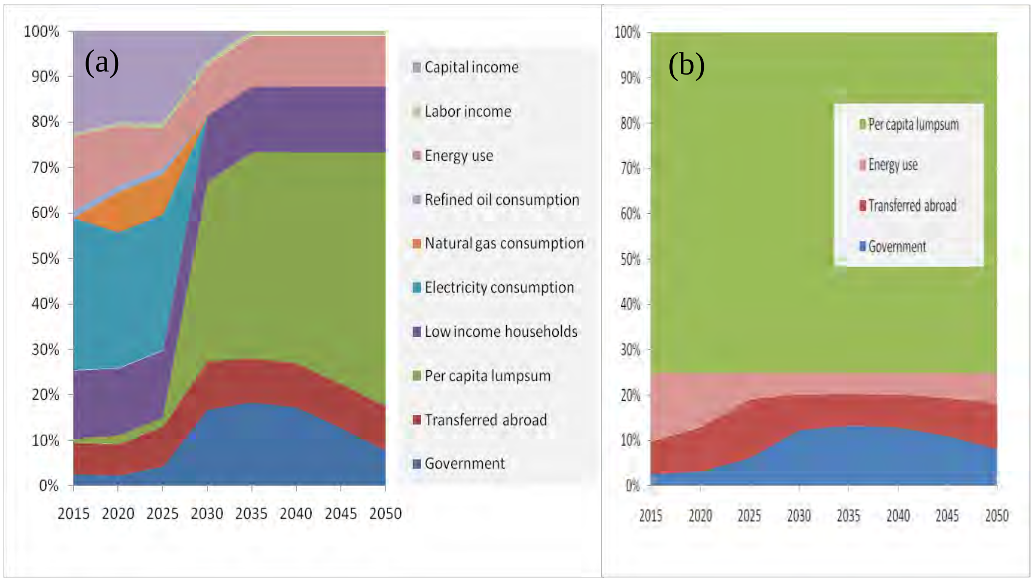

Figure 3. The Allocation of Allowance Value according to Model Distribution Instruments: **(a)** Targeted Allowance Allocation Scheme, **(b)** Per Capita Dividend Scheme.

production on the basis that these industries are most likely to be affected by unemployment as the country shifts away from fossil fuels. We distribute funds devoted to CCS along with other energy R&D funds.

Given this mapping of the allocation provisions in the various legislative proposals we construct **Figure 3** that is similar to Figure 2 but showing instead the allocation of allowance value mapped to the instruments we use in USREP. The distribution instruments for all of these uses, except Foreign and Government, direct revenue to households but the particular instrument determines how the allowance value is allocated among households in different regions and in different income classes. As modeled, allowance value allocated abroad has no value for U.S. households. In the proposed legislation, most of the allowance value distribution is a pure transfer but some of these program expenditures are intended to incentivize energy savings and the like. Our allocation approach treats all of these program expenditures as pure transfers.[16] To the extent these programs overcome barriers that are not addressed by the CO_2 price, additional efficiency gains would reduce the welfare costs we estimate. To the extent these programs create double-incentives for particular activities, then they

[16] We assume that the 25% of allowances in the Cantwell-Collins bill that go to a dedicated trust to fund climate mitigation and adaptation, clean energy and efficiency, and transition assistance programs, are allocated according to residual shares for similar categories (Energy use, Foreign, Government) in the Waxman-Markey bill. We understand that additional legislation would be needed to appropriate this allowance revenue to the purposes identified in the legislation, and absent that the revenue would be returned to the Treasury.

are redirecting abatement to activities that are not the most cost effective and that would increase the welfare cost we estimate. The assumption that they are pure transfers is therefore a neutral assumption. Furthermore, note that transfers of allowance value to households are treated as being non-taxable, with the effect of increasing how much allowance value must be set aside relative to a scenario where such transfers are taxed.

Allowances allocated to government reduce the need for capital and labor taxes to be raised as much to meet the revenue neutrality assumption we impose[17], and so affect the distribution to households based on how increases in taxes affect different regions and income classes.

5. SCENARIO DESIGN

We distinguish two sets of scenarios that differ with respect to the underlying allowance allocation scheme. Scenarios labeled *TAAS* represent a Targeted Allowance Allocation Scheme that is based on the Waxman-Markey or Kerry-Lieberman proposal. The *TAAS_DR* scenario sets aside a larger amount of allowances for the purpose of Deficit Reduction (Deficit Reduction) as in the allocation rule proposed by Kerry-Boxer. Scenarios labeled *PCDS* model a simple Per Capita Dividend Scheme as described in the Cantwell-Collins proposal.

For each of the proposed allocation schemes, we design two scenarios that differ with respect to how the revenue neutrality requirement is met.[18] Our base case assumption is that sufficient allowance revenue is withheld by the government to cover the deficit impact and the remaining revenue is allocated at the percentages shown in Figure 3. An alternative case, denoted *TAX*, assumes that only the amount of allowance revenue specifically designated for deficit reduction in the bills is allocated to the government. We then raise capital and labor taxes uniformly across regions and income classes (in percentage points) to offset revenue losses from carbon pricing. This is separate from any allowance revenue targeted to deficit reduction. All scenarios assume the medium offset case from the analysis carried out in Appendix C of Paltsev *et al.* (2009) with identical assumptions about supply and costs of domestic and international offsets. We further assume that offsets have a cost to the economy, and implement this assumption by transferring abroad the value of allowances purchases internationally. Our assumption is that the average cost of these credits is $5 per effective ton of offsets of CO_2-e in 2015, rising at 4% per year thereafter.[19] Also

[17] See Section 5 for a discussion of our treatment of revenue neutrality.

[18] We fix government spending in the policy scenarios to match government spending under the reference scenario. Since government spending does not enter household utility functions, we did not want to confound welfare impacts from changes in the size of government with welfare impacts of climate policy. We discuss the implications of this assumption in section 6.1 below. Government spending in the reference scenario is assumed to growth in proportion with aggregate income.

[19] The Waxman-Markey bill specifies that 1.25 tons of foreign reductions are required to produce 1 ton of effective offsets. The $5/ton initial offset price means the actual payment per ton of foreign reduction is $4. For all proposals analyzed, we treat offsets costs symmetrically.

Table 4. Correspondence between Proposals Allowance Value Allocations and Distribution Instruments in USREP.

ALLOWANCE RECIPIENTS	MODEL INSTRUMENT
Mitigating Price Impacts on Consumers	
All electricity local distribution companies (LDCs)	Lump-sum transfer to consumers. Allocated to regions based on GHG emissions (50%) and based on value of electricity consumption (50%). Within a region, allocated to households based on the value of electricity.
Additional allowances for small electricity LDCs	Lump-sum transfer to consumers. Allocated to regions based on GHG emissions (50%) and based on value of gas consumption (50%). Within a region, allocated to households based on the value of gas consumption.
Natural gas LDCs	Lump-sum transfer to consumers based on value of gas consumption.
State programs for home heating oil, propane, and kerosene consumers	Lump-sum transfer to consumers based on value of oil consumption (excluding oil consumed for transportation purposes).
Assistance for Households and Workers	
Protection for low-income households	Lump-sum transfer to households with annual income less than $30k.
Worker assistance and job training	Distributed to regions based on value of energy production (coal, crude oil and refined oil). Within a region, distributed across households base on wage income.
Per-capita consumer rebate	Lump-sum transfer based on per-capita.
Nuclear working training[1]	Distributed to regions based on value of nuclear electricity generation. Within a region, distributed across households based on wage income.
Allocations to Vulnerable Industries[2]	Lump-sum transfer based on capital income.
Technology Funding[3]	Distributed to regions based on energy use (industrial and private). Within a region, distributed based on household energy consumption.
International Funding[4]	Transferred abroad.
Domestic Adaptation	Distributed to government.
Other Uses	
Deposited into the Treasury (to offset the bill's impact on the deficit)	Distributed to government.
Grants to state and local agencies for transportation planning and transit[1]	Distributed to government.
Compensation for "early action" emission reductions prior to cap's inception	Distributed to households on a per capita basis.
Allowances already auctioned in prior years	46% distributed to households on a per-capita basis, 54% distributed to government.[5]
Strategic reserve allowances	Distributed to households on a per capita basis.

Note: [1]This allowance category only applies to the Kerry-Boxer bill. [2]Allocations to vulnerable industries include: Energy-intensive trade-exposed (EITE) industries, all petroleum refiners, additional allowances for small refiners, merchant coal-fired electricity generators, generators under long-term contracts without cost recovery, cogeneration facilities in industrial parks. [3]Technology Funding includes: Carbon capture and sequestration (CCS) incentives, state renewable energy and efficiency programs, state building retrofit programs, incentives for renewable energy and agricultural emissions reductions, clean vehicle technology incentives, energy innovation hubs, energy efficiency and renewable energy worker training fund, advanced energy research, supplemental reductions from agriculture, abandoned mine land, and renewable energy. [4]International Funding includes: International avoided deforestation, international clean technology deployment, and international adaptation. [5]We allocate allowances that are already auctioned in prior years to the government and to households according to the respective average share over the period from 2012-2050.

note that since we create more allowance revenue for the government by increasing the allowances to account for credits coming from outside the system, we assume that the income transferred abroad to account for permit prices is taken from the allowance revenue. Finally, our assumptions about the supply of offsets imply a 203 bmt cumulative emissions target for 2012-2050, which underlies all of the scenarios we consider here.

Our analysis also takes banking and borrowing into consideration. In the Waxman-Markey bill, banking of allowances is unlimited and a two-year compliance period allows unlimited borrowing from one year ahead without penalty. Limited borrowing from two to five years ahead is also allowed, but with interest. In general, we find no need for aggregate borrowing, and so there is no need to implement an explicit restriction on it.

Our scenarios draw on features of the proposed pieces of legislation described above but in no way purport to model them in their entirety. Our focus is on the efficiency and distributional consequences of allowance allocation schemes and our scenarios model allowance trading along with their allocation over time. In that regard, we have had to interpret how we believe various allocations would work in practice when the exact allocation approach has not yet been fully described, and would only be completely determined by executive branch agencies responsible for these programs if the legislation were implemented. In addition, we do not model other components of the various pieces of legislation dealing with other policy measures such as renewable portfolio standards.

6. ANALYSIS OF SCENARIOS

Figure 4 shows the *Reference* and *Policy with offsets* emissions for the period 2012 to 2050. Projected *Reference* cumulative emissions over the 2012-2050 period are 298 bmt. In the *Policy with offsets case*, cumulative emissions are 203 bmt, a reduction of nearly one-third from Reference. The emissions path shown in Figure 4 for the *Policy with offsets case* is the result from the scenario *TAAS*. Cumulative emissions are identical under all six policy simulations, and the actual emissions paths are nearly identical. Slight differences in the emissions paths exist because of different overall welfare costs and distributional effects that can lead to a slightly different allocation of abatement over time, but these differences are so small that they would be imperceptible if plotted in Figure 4. Emissions in the *Reference* include estimates of the effects of existing energy policies under the Energy Independence and Security Act and the American Recovery and Reinvestment Act as they are projected to affect greenhouse gas emissions. Note, that while the allowance allocation for 2050 is set at 83% below 2005, our projected emissions in 2050 in the *Policy with offsets* case are only 35% below 2005 emissions because of the availability of offsets and banking. Before turning

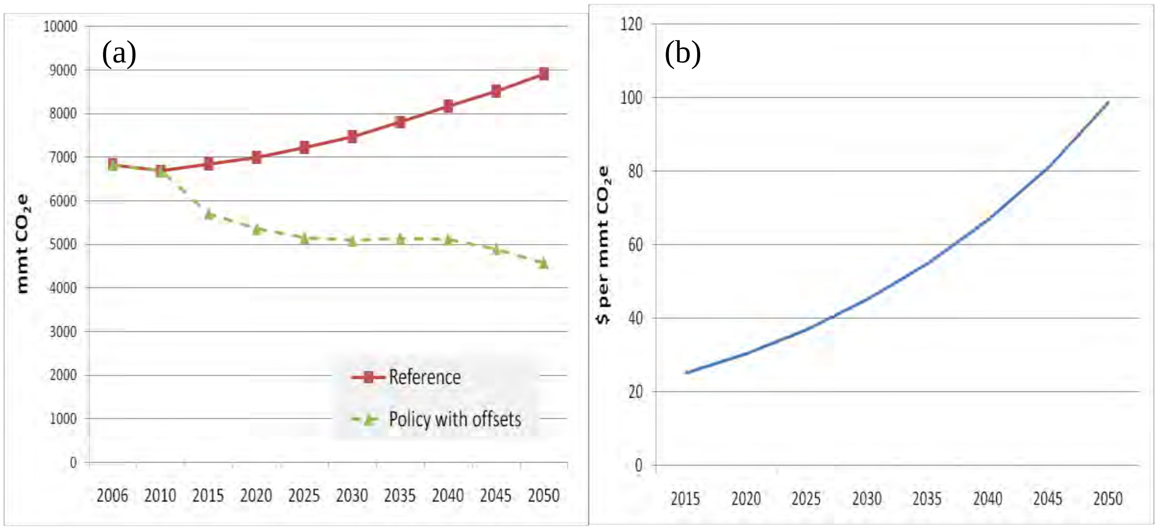

Figure 4. U.S. Greenhouse Gas Emissions and Carbon Price (Scenario *TAAS*): **(a)** Greenhouse Gas Emissions, **(b)** CO_2e Price.

to distributional analyses by income group or region, we consider the aggregate U.S. welfare impacts of the various policies we model. **Figure 5** presents the change in welfare relative to the *Reference* scenario, measured in equivalent variation as a percentage of full income[20], for the various bills. One key result we see is that the *_TAX* scenarios lead to higher welfare costs than the scenarios where a fraction of the allowance revenue is withheld to satisfy revenue neutrality. Considering the *TAAS* scenario, for example, the welfare cost is 1.38 percent of full income by 2050 under the lump-sum scenario and 1.60 percent under the tax scenario. Similar results hold for *TAAS_DR* and *PCDS*. This occurs because the *_TAX* scenarios create more deadweight loss from capital and labor taxation. Many economists have focused on a double-dividend effect where allowance revenue is used to lower capital and labor taxes, but here we have the reverse effect. Not enough of the revenue is retained to offset the deficit effects of the bill so that capital and labor taxes need to be increased, thereby increasing the cost the bill.[21]

Conditional on the treatment of revenue shortfalls, the three scenarios have very similar aggregate costs. *TAAS_DR_TAX* is somewhat less costly than *TAAS_TAX* because the former scenario reserves more of the allowance to offset the deficit and thus capital and labor taxes do not need to be increased as much. The costs of *PCDS* and *PCDS_TAX* are slightly lower than the *TAAS* scenarios. The lower costs of the *PCDS* scenarios at first blush are surprising. These scenarios retain less of the allowance value

[20] Full income is the value of consumption, leisure, and the consumption stream from residential capital.
[21] This follows from our particular assumption about how taxes are raised to maintain revenue neutrality. It is certainly possible that lump-sum taxes could be employed or some other configuration of tax increases that is less distortionary than the tax increases we model. Therefore one should not conclude that our result is general.

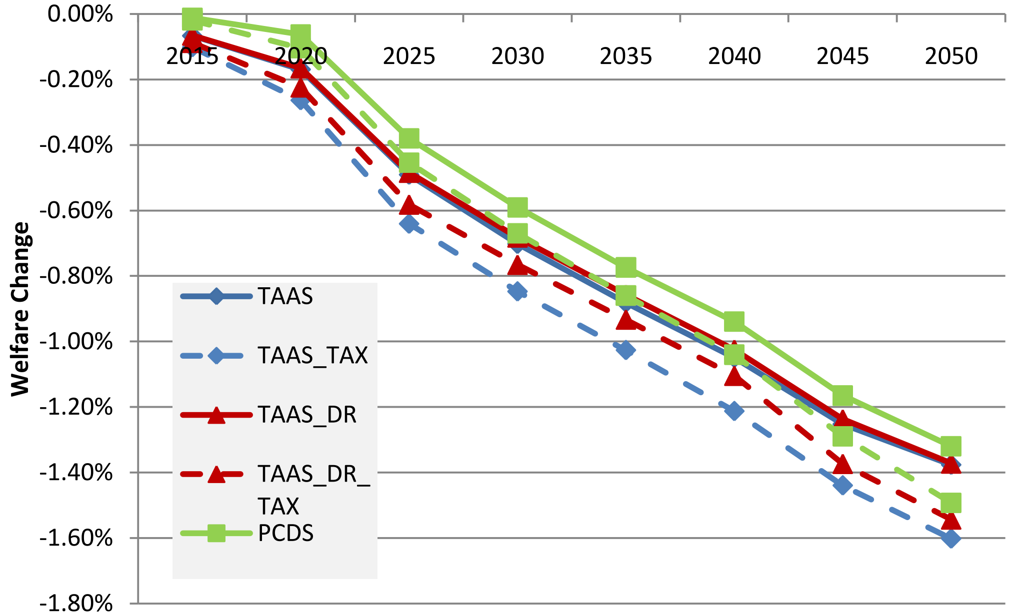

Figure 5. Welfare Change for Different GHG Control Proposals (U.S. Average).

to offset the deficit, and hence in the *_TAX* case it requires somewhat higher increases in capital and labor taxes to offset the deficit. The lower costs in *PCDS* scenarios arise from the distributional outcomes as they affect energy expenditures and savings. In particular, *TAAS* and *TAAS_DR*, through the low income energy assistance programs allocate more of the revenue value to poorer households. Lower income households spend a larger fraction of their income on energy and they save less. Thus, the abatement effect of pricing carbon is offset to greater extent by an income effect among poorer households in the *TAAS* and *TAAS_DR* than in the *PCDS* scenarios. In addition, there is less saving and therefore less investment in *TAAS* and *TAAS_DR* because less is saved for each additional dollar allocated to poorer households. Note that our aggregate welfare estimates are a simple sum of the welfare of each income class across all regions. An aggregate welfare function that weighted the welfare of lower income households higher, giving welfare benefit to more progressive outcomes would change these results, showing better results for *TAAS* and *TAAS_DR*. How much to value more progressive outcomes is a judgment. Here we leave it to the policy community to decide whether the more progressive outcome of *TAAS* and *TAAS_DR* is worth the extra welfare cost.

6.1 Distributional Impacts across Income Groups

Aggregate impacts obscure differential effects across households. Ideally we would construct a measure of the lifetime burden of carbon pricing and relate that to a measure of lifetime income. Our data do not allow us to do that. Our recursive-dynamic model

Table 6. Annual Cost per Household by Income Group (Scenario *TAAS*).

	hhl	hh10	hh15	hh25	hh30	hh50	hh75	hh100	hh150	Average
2015	-614	-472	-467	-426	36	261	328	344	401	87
2020	-563	-412	-418	-349	230	386	532	501	532	221
2025	-450	-248	-207	-64	631	920	1109	1098	1237	646
2030	-603	-240	-168	63	950	1420	1589	1650	2031	939
2035	-763	-304	-190	110	1170	1842	2050	2192	2758	1195
2040	-851	-307	-156	203	1397	2222	2456	2636	3304	1451
2045	-827	-216	-13	411	1658	2661	2916	3141	3918	1774
2050	-778	-109	129	594	1853	2974	3246	3482	4278	2008
NPV Average[a]	-291	-150	-119	-33	331	538	614	642	780	347

Note: Table reports annual dollar costs per household by income group in various years. All dollar amounts are in 2006 dollars. [a] Net Present Value (NPV) average of welfare costs discounted to 2010 at 4% per annum.

has households of different income groups in each year but we have no data that allow us to track the transition of households from one income group to another. Instead we report burden impacts for different income groups at different points of time to show how the relative burden shifts over time.

Figure 6 shows the burden for a representative household in each income group for 2015, 2030, and 2050 for *TAAS* measured as equivalent variation divided by full income (including the value of leisure and household capital). Positive values indicate that a household benefits from the carbon policy. Households in the two lowest income groups, *hhl* and *hh10*, benefit in all periods as the return of permit revenue through various mechanisms more than offsets the higher cost of goods and services due to carbon pricing and any effects on their wages and capital income. Households *hh15* and *hh25* initially benefit but eventually bear net costs, *hh15* only in the final period. The effect of allocating an increasing amount of allowances on a per-capita basis is particularly strong for the lowest income group relative to higher income households since a dollar of additional revenue makes up a larger fraction of full income for these households.[22] The five highest income households bear net costs throughout the period though the burden through 2030 is less than 1 percent of income for all income groups.

[22] Pechman (1985) realized that income data for the low income groups suffered from substantial income mismeasurement. Since then, the approach adopted by him and many others is to omit the lowest income group from distributional analyses. Given the interest of the policy community for impacts on low income households, we decided to report results for households with annual income less than $10k, but we want to point out that in light of likely measurements problems we do not have the same degree of confidence in results as we do for other income groups.

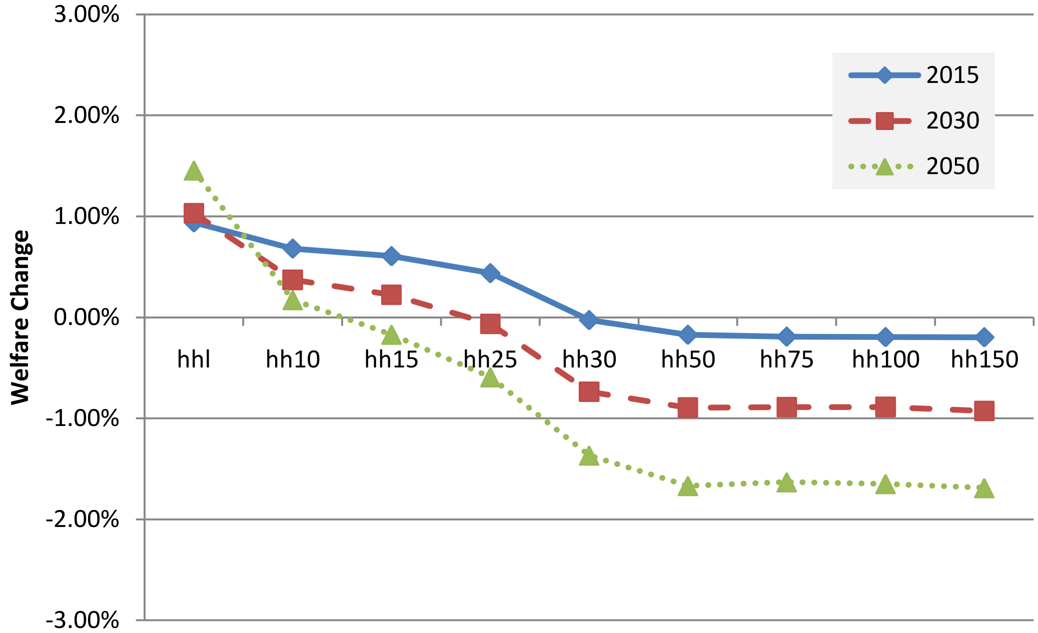

Figure 6. Welfare Change by Income Group, U.S. Average (Scenario *TAAS*).

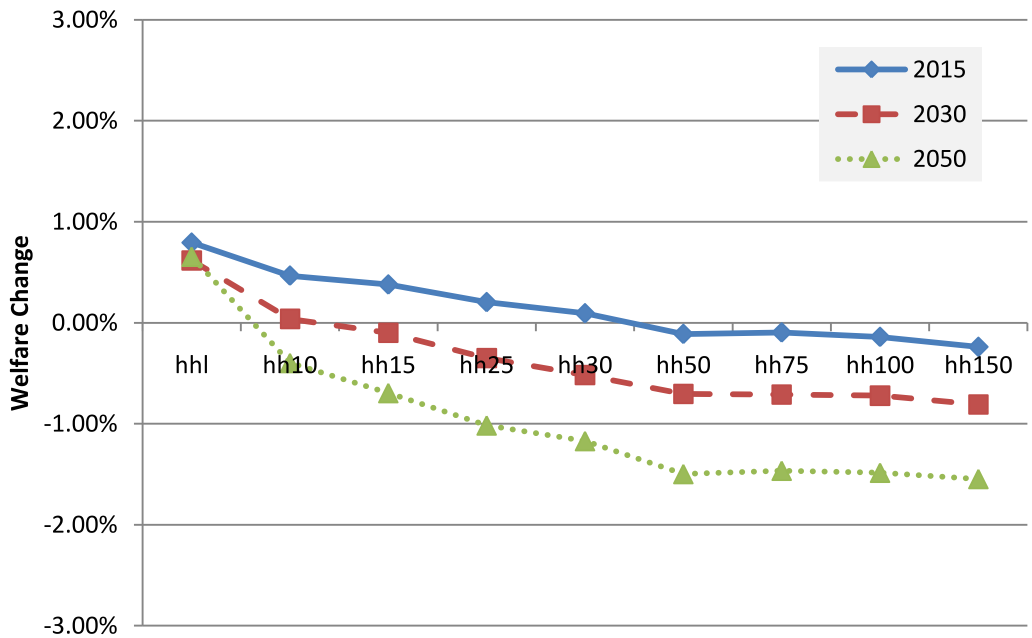

Figure 7. Welfare Change by Income Group, U.S. Average (Scenario *PCDS*).

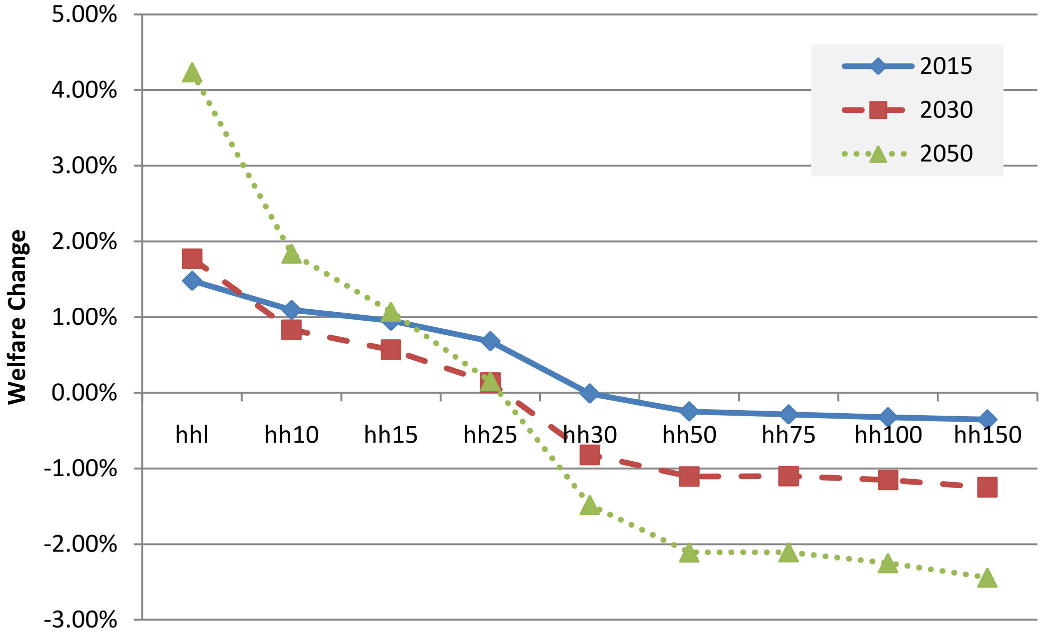

Figure 8. Welfare Change by Income Group, U.S. Average (Scenario *TAAS_TAX*).

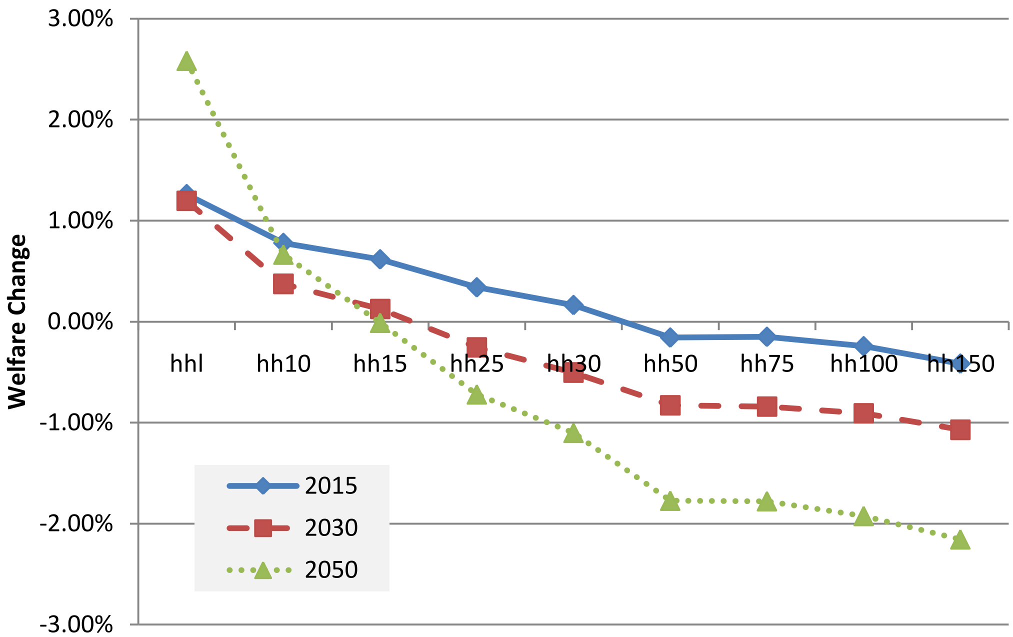

Figure 9. Welfare Change by Income Group, U.S. Average (Scenario *PCDS_TAX*).

Table 7. Allocation Of Annual Allowance Value And Tax Revenue (Scenario *TAAS*).

Allowance Values and Tax Revenue				Allocation of Allowance Value (Net of Tax Revenue Loss)		
Year	Allowance value	Loss in tax revenue[a]	Loss in tax revenue (% of allowance value)	Households	Government	Transferred abroad
2015	160.6	50.3	31.3	99.8	2.9	7.6
2020	182.9	52.2	28.5	113.0	2.9	9.0
2025	212.7	72.3	34.0	115.9	5.9	12.4
2030	254.1	73.1	28.8	131.5	30.2	19.3
2035	309.5	91.0	29.4	157.3	40.0	21.2
2040	374.0	124.4	33.3	182.4	43.0	24.2
2045	434.4	182.8	42.1	195.4	31.8	24.4
2050	494.7	248.8	50.3	203.0	19.1	23.9

Note: Unless otherwise stated, all amounts are in billions of dollars. [a] Change relative to the baseline.

Over time, the burden of the policy grows for wealthier households with the burden ranging from 1 to roughly 1.5 percent by 2050.

In all years the cap and trade policy combined with the *TAAS* allocation scenarios is sharply progressive over the first five income groups though the burden for each income group, except that of the lowest, grows over time as the policy begins to impose larger reductions in emissions. The difference in burdens over the lowest five income groups grows over time as does the spread between the burden for the lowest income group relative to the highest income group. The policy is essentially neutral over the top income groups in all periods. As we will show below over time sources side effects become more important in shaping the distributional outcomes than do uses side effects.

Table 6 reports the annual cost in dollar terms for different households in different years. On average the per-household costs are relatively modest in the early years of the program. While the costs appear large by 2050, it is important to keep in mind that incomes are growing so that these costs are still modest relative to household income. The average over time is the net present value (NPV) average. Note that Waxman-Markey allows considerable borrowing of allowances from the future by the Federal government if necessary to moderate CO_2 prices in the early years. If these were auctioned in earlier years then the allowance revenue would accrue to the government earlier and in principle it could be used earlier. We have assumed the revenue is only available when the allowances were originally scheduled to be auctioned. If borrowing occurred and the revenue was used as specified in the bill—to reduce deficit impacts and as a lump sum rebate to consumers - that could blunt some of the progressivity in earlier years.

Costs and distributional impacts for *TAAS_DR* are very similar to *TAAS* and so we

Table 8. Increase In Marginal Personal Income Tax Rate for Revenue Neutrality.

Year	TAAS_TAX	TAAS_DR_TAX	PCDS_TAX
2015	0.52	0.34	0.48
2020	0.56	0.35	0.43
2025	0.73	0.50	0.58
2030	0.58	0.26	0.55
2035	0.63	0.31	0.65
2040	0.80	0.35	0.83
2045	1.13	0.58	1.12
2050	1.50	0.79	1.48

Note: Tax rate increase in percentage points.

do not report them here. Rather we turn to the *PCDS*. Like *TAAS* and *TAAS_DR*, *PCDS* has modest to negative burdens initially with burdens rising over time. In comparison to the former bills the burden spreads across income groups in any given year are smaller. Lower income households benefit in the early years but not as much as in *TAAS* and *TAAS_DR*. This is reflected in the flatter distributional curves for different years in **Figure 7**. By 2050 the *PCDS* scenario and the *TAAS* scenario have more similar distributional effects because by that time the allocation formula in *TAAS_DR* has become similar to that of the *PCDS*, with 65 percent of revenue distributed on per capita basis. The remaining difference is the continued allocation to low income consumers.

Distributional outcomes are altered when the full value of allowances is allocated as specified in the bills and revenue losses in the federal budget are instead made up by raising personal income tax rates. In general, the distributional burden across household groups is more progressive in the ***_**TAX* cases. Consider the burden snapshots for three different years as shown in **Figure 8** for *TAAS_TAX*. Lower-income households fare better under this approach with benefits to the lowest income group rising from 1 to about 1.5 percent of full income in 2015 while the highest income groups are only slightly affected. Lower income groups continue to do better – and in some cases are better off – when tax rates are raised to recoup lost tax revenues than when allowance value is withheld. In general they remain better off through 2050 because of the tax changes. By raising taxes to offset the deficit, more revenue remains available to be distributed, and the increase in transfers to lower-income groups more than offsets increases in taxation to these households. A similar result holds for the *PCDS* allocation proposal (see **Figure 9**).

The different treatments of revenue neutrality illustrates a classic equity-efficiency trade-off, where the withholding of allowances to preserve revenue neutrality yields higher efficiency but less progressive outcomes than if taxes are raised to maintain revenue neutrality in the government budget.

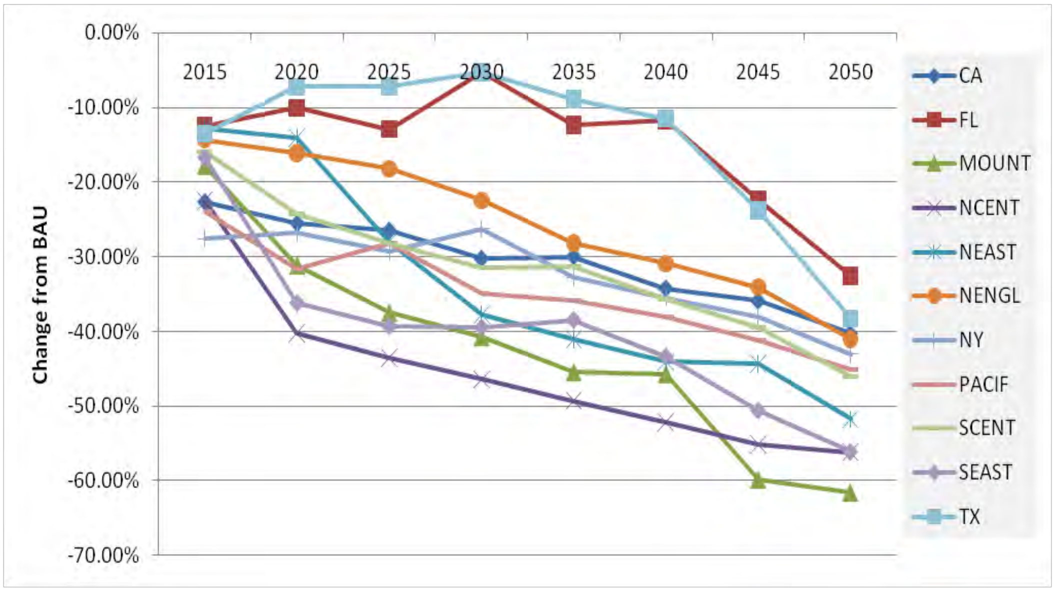

Figure 10. GHG Emissions Reductions by Region (Scenario *TAAS*).

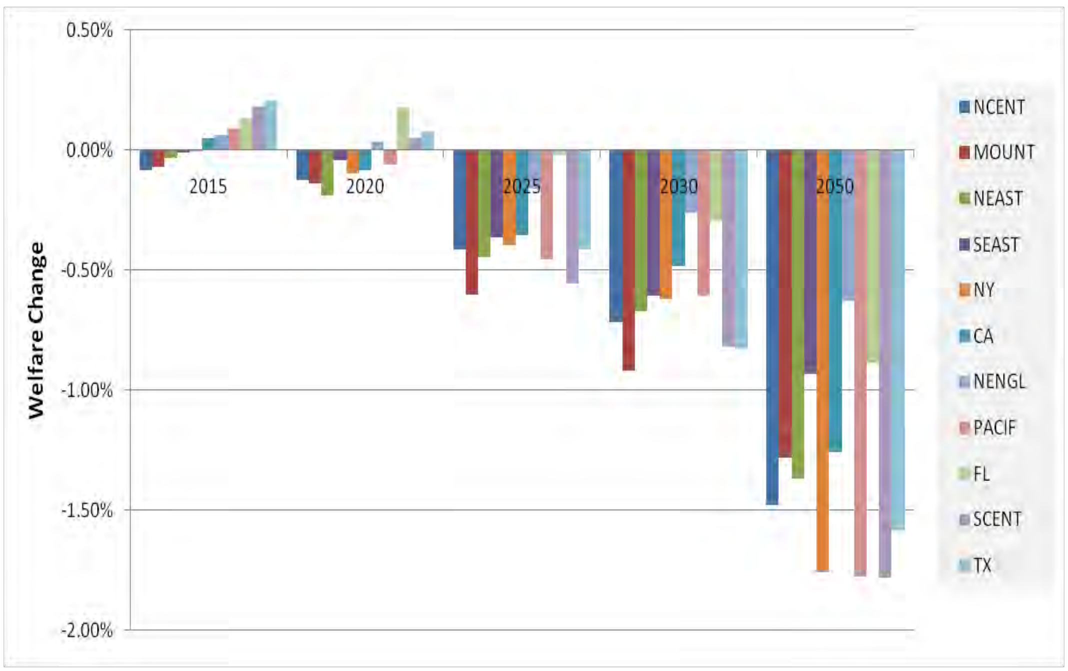

Figure 11. Welfare Change by Region (Scenario *TAAS*).

The impact of climate policy on government tax revenues is significant and helps explain why the different approaches to maintaining revenue neutrality matter. **Table 7** provides a comparison of allowance values and losses in tax revenue arising from cap-and-trade policy. The initial loss of tax revenue due to higher costs for firms and reduced economic activity is about 30 percent of the value of allowances. The percentage begins rising in 2040 and by 2050, the loss in tax revenue rises to one-half.

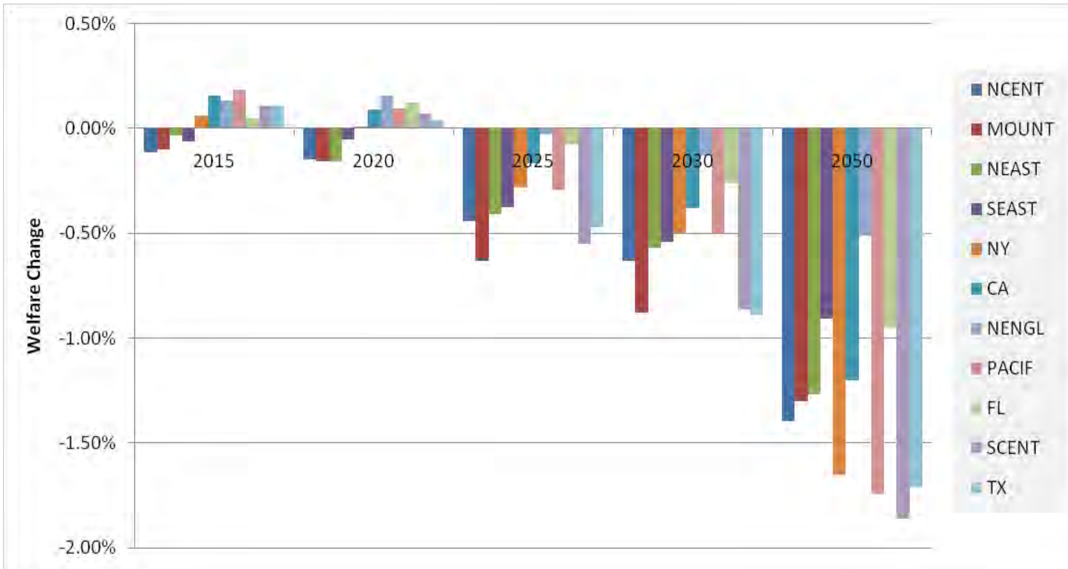

Figure 12. Welfare Change by Region (Scenario *PCDS*).

The high tax revenue loss is in part an artifact of the assumption in the model that fixes the path of government spending to match that of the reference (no policy) scenario (we refer to this as absolute revenue neutrality). Lower GDP growth increases the size of government relative to GDP and magnifies the loss in tax revenue relative to allowance value. We make this assumption because the government sector in USREP does not produce explicit public goods that have any welfare value. By keeping revenue neutral changes in government we do not release or consume more resources that otherwise would be available to private sector.

An alternative approach would be to fix the ratio of government spending to GDP in the policy scenarios. To assess the distributional implications of this would then require production of a public good and an estimate of how that public good created welfare for different income classes in different regions, so that when government spending was increased or decreased we would have an estimate of how that was affecting distribution compared with how distribution was affected by changes in resources available to the private sector. If the government were kept at the same size in relative rather than absolute terms, the revenue needed to offset impacts on the deficit would not increase and would generally be at about the percentage we see in 2015. The difference would then be additional allowance value that could be used for distributional or other purposes.

We note that the Congressional Budget Office scores bills on their impact on the deficit, using a standard procedure for all legislation that is accepted by Congress. The CBO methodology is described in Congressional Budget Office (2009). That approach will not be consistent with our approach that endogenously calculates the deficit, and the revenue needed to close the deficit. The two approaches do lead to reasonably close estimates of the allowance value that must be set aside in early years (25 percent for CBO and 30 percent in this analysis) before the results diverge due to the different modeling approach taken by CBO from the approach taken here.

With absolute revenue neutrality, the need to make up substantial revenue losses leads to fairly large increases in marginal personal income tax rates under the tax-based make-up (see **Table 8**). The *TAAS_DR_TAX* increases are much less than the other two scenarios because more of the revenue is explicitly allocated to deficit effects of the proposal. This just illustrates one way to make up revenue losses. Other approaches could be undertaken that could enhance efficiency or equity goals.[23]

Summing up, we find that the *TAAS* and *TAAS_DR* scenarios on the one hand and the *PCDS* scenarios on the other have quite different distributional impacts across households, especially in the early years of the program. In addition, policy decisions on how to close the budget deficit arising from decreased tax collections have both efficiency and distributional implications.

Using higher personal income taxes to close the deficit incurs an efficiency cost but increases the progressivity of the programs because more of the allowance revenue is available for distribution to households. We next turn to regional impacts.

6.2 Distributional Impacts across Regions

Policy makers have also expressed concern over the regional impacts of climate policy. In this section we explore how regional impacts change over time for the allocation scenarios we have designed. **Figure 10** shows that the greenhouse gas emission reductions differ substantially among regions. Results are shown for the *TAAS* scenario. These differences reflect different shares of emissions from different sectors (electricity, transportation, industry) and different electric generation technologies (nuclear, hydro, coal, natural gas). The energy and emissions intensive regions (MOUNT, SEAST, SCENT, NCENT) show the largest reductions. States in the Mountain, Southeast, Northeast and North Central regions all experience reductions in GHG emissions relative to the business as usual scenario in excess of 50 percent by 2050.

Figure 11 shows the welfare impact of the *TAAS* scenario for each region. Initially California, Texas, Florida and states in the South Central, Pacific, and New England regions gain from the policy while other states suffer losses. By 2050 all states are bearing costs, ranging from about one-half of one percent (New England) to about one and three-quarters percent.

Welfare impacts for Alaska are not shown in Figure 11 to better visualize relative welfare impacts for other regions. Under the *TAAS* scenario Alaska's welfare effects are as follows: 2015: -0.42%; 2020: -1.15%; 2025: -2.26%; 2030: -2.57%; 2040: -

[23] This is simply a variant on the green tax swap idea analyzed by Metcalf (1999) and others.

3.52%; 2050: -5.27%. The substantial welfare impacts for Alaska can be attributed to the fact that Alaska exhibits by far the highest energy intensity among all regions and is a large energy producing state with a small population (see **Figure 14**). In earlier years of the policy, welfare effects are relatively modest compared to, e.g., 2030 and 2050. Alaska actually receives by far the highest allowance revenue per household among all regions under the *TAAS* scheme since many of the allowances are allocated on the basis of either energy consumption or production, but this is far from sufficient to offset the large costs the economy bears. As we note below, over time the allowance allocation effect becomes less important in determining overall policy costs, and relative regional welfare differences are increasingly shaped by energy characteristics and income sources. This explains why welfare effects for Alaska become more negative over time both relative to earlier periods of the policy and in comparison to other regions. The Alaska case is an interesting one in that it is a small state in terms of population and GDP with relatively unique energy use and production attributes. Our other regions, by aggregating more states, tend to average out so that there is less disparity. The Alaska results are illustrative of within region effects that we do not capture because of our aggregation.

Regional impacts under *PCDS* are less balanced initially (**Figure 12**). The standard deviation of welfare impacts under *PCDS* is slightly larger (0.11) than under the *TAAS* scenario (0.09). Recall that *PCDS* deliberately takes a per-capita approach premised on the view that regional disparities do not matter, while *TAAS* includes a number of provisions (such as LDC allocations) that are explicitly intended to address regional disparities. While the regional dispersion of welfare impacts is slightly larger under *PCDS*, one interesting result of this analysis is that the much simpler per-capita based approach is almost as effective in achieving a balanced regional outcome as the targeted allocation scheme. By 2050, the impacts under *PCDS* are quite similar to those under *TAAS*. Differential regional impacts due to differences in allowance allocation schemes dissipate over time. Section 7.1 provides a discussion of this effect.

Impacts under *TAAS_DR* are very similar to those under *TAAS* and are not reported here. Figure 12 also shows that the relative impacts across regions are fairly stable over the policy period under the PCDS allocation. South Central, North Central and Northeast states bear a larger impact of the policy though the maximum difference across the period is less than two percentage points.[24]

We do not show here the *_TAX* scenarios because the results are broadly similar to the scenarios where a fraction of the allowance value is withheld to satisfy revenue neutrality. The main differences are that the overall welfare costs are larger for the U.S.

---

[24] Welfare impacts for Alaska under the *PCDS* scenario are as follows: 2015: -0.60%; 2020: -1.10%; 2025: -2.31%; 2030: -3.25%; 2040: -4.61%; 2050: -5.95%. Note that under the *PCDS* allocation scheme Alaska receives less allowance revenue as compared to the *TAAS* case. This lowers savings and investment, and hence brings about even larger welfare losses in later periods of the policy as for the *TAAS* scenario.

as a whole and thus regional losses tend to be somewhat larger. In terms of distribution, the *_TAX* cases tend to favor lower income regions (South and middle of the country) at the expense of higher income regions (mainly the East and West coasts) because higher income regions pay more taxes.

Summing up the regional results, all allocation scenarios lead to modest differential impacts across most regions. The *TAAS* and *TAAS_DR* proposals show greater gains to several regions in the initial years of the policy and higher costs to other regions than do the *PCDS* scenarios. One of the political economy realities of climate change is that the East and West Coast regions have pushed harder for climate legislation while the middle of the country and much of south has resisted such legislation. With high energy intensity in these regions and the significant presence of fossil industry one might expect greater economic impacts of GHG mitigation legislation in these regions. The Cantwell-Collins bill has not been subject to as much debate and negotiation as the other two bills, and has been able to retain a simple allocation formula. The much richer set of allocation mechanisms in Markey-Waxman and Kerry-Boxer are likely the result of negotiation among representatives of these regions. To the extent our analysis captures the regional distributional intent of these bills it suggests that the allocation formula are not completely effective in evening out regional effects. Some states like Texas and those in the South Central region that might have been expected to suffer higher costs have those costs blunted significantly and actually come out ahead in early years. Other regions such as the Mountain and North Central states remain the biggest losers in early years. Over time the allocation mechanisms evolve, and regional impacts are driven more directly by other factors.

7. FURTHER ANALYSIS OF THE BURDEN RESULTS

In a CGE model it is difficult to attribute differences in results by region and income class to specific causes because the possible sources of differences are many and they interact in complex ways. This section provides an analysis of the results to provide greater insight into why we see differences in effects.

7.1 The Importance of the Allowance Allocation Effect over Time

In order to isolate the impact of the allowance allocation on welfare, we run a scenario assuming the allowance value in a given period is not recycled while allowances in preceding periods are allocated according to the scheme described in the TAAS scenario.

Note that welfare costs will be higher in this case because the unrecycled revenue increases government expenditure which as described earlier does not, as modeled, enter household utility functions. The intent here is to use this exercise to isolate the effects of higher energy costs caused by pricing from those distributional impacts that

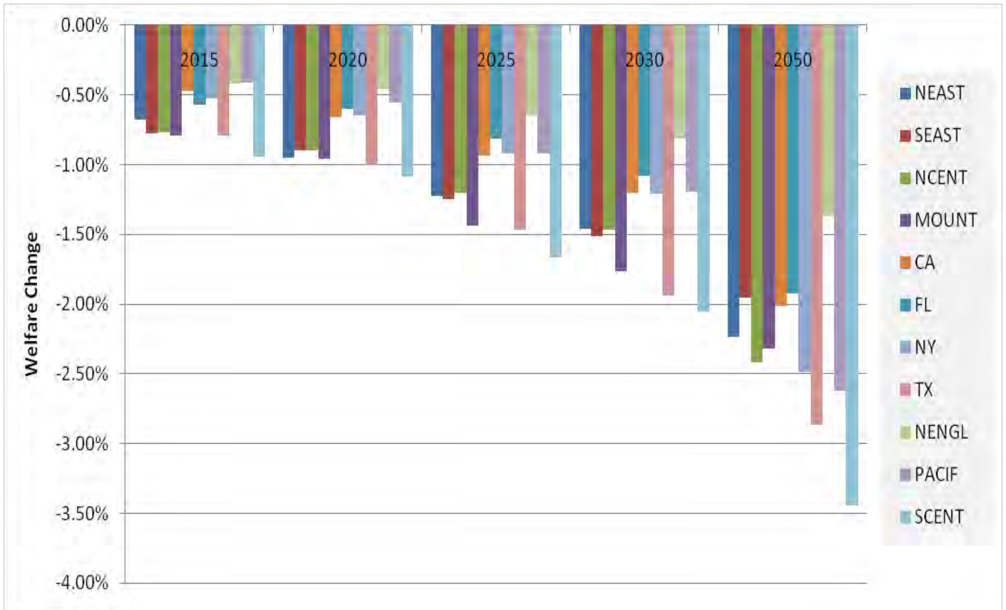

Figure 13. Regional Welfare Impacts without Allowance Allocation (Scenario *TAAS*).

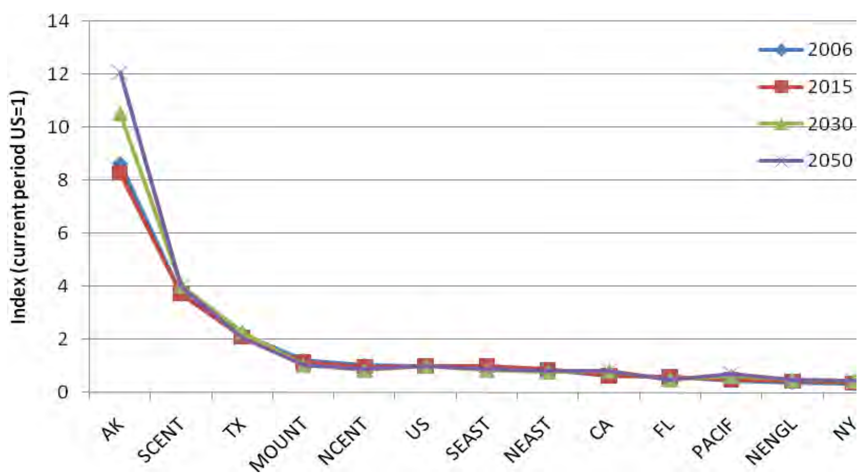

Figure 14. Regional Energy Intensity over Time (Scenario *TAAS*).

result from the allowance allocation. **Figure 13** shows regional welfare impacts under this "no-recycling" case. As expected, welfare costs for each region and each period are higher as compared with the corresponding scenario that assumes revenue allocation (compare with Figure 14). For 2015, the distribution of regional costs is due to differences in regional abatement costs. In later years, the results are driven by abatement costs for that year, and the economic growth effects from previous years through the impact on Gross Regional Product and savings and investment. We see from Figure 13 that the pattern of regional welfare costs corresponds closely to differences in regional energy intensity (energy consumption per dollar of GDP). Figure 14 shows an index of energy intensity by region over time (normalized to the current period U.S. value). The patterns of regional welfare impacts and relative energy intensities largely coincide, and are stable over time.

Comparing Figure 13 with Figure 11 now provides a way of disentangling the effect of the current period allowance allocation on welfare. The key result is that the allocation effect becomes less important over time, and that regional welfare impacts are eventually driven more by differences in the energy intensity. One reason for this result is that over time there is less allowance value to be distributed relative to the rising CO_2 price as the carbon policy becomes tighter. The number of allowances decreases over time and, in addition to that, the erosion of the tax base is steadily increasing which means that more of the allowance value has to be retained to maintain revenue-neutrality. This effect explains why initially in periods 2015-2025 the allocation of allowances has a strong effect on regional welfare impacts of the policy. As noted, regional effects of *TAAS* bear little relationship to factors like energy intensity and energy production that should factor into the cost of the policy. Some of the regions that display relative high energy intensity are actually overcompensated in 2015 and 2020 (viz. the South Central and North Central region, and Texas). The results suggest that any implemented allocation scheme will prove to be less effective over time in muting the regional variation in welfare impacts.

7.2 Sources vs. Uses Side Impacts of Carbon Pricing

A well-established observation is that carbon pricing incorporates a regressive element because lower income households spend a higher proportion of their income on energy. Most estimates of the distributional impact of carbon and energy pricing focus on this “cost-push analysis” element of carbon pricing by using an Input-Output framework to trace price increases through a make-and-use matrix to evaluate the policy cost on different households based on expenditure shares (e.g., Dinan and Rogers (2002), Parry (2004), Burtraw *et al.* (2009) and Hassett *et al.* (2009)). Such an approach neglects behavioral responses to relative price changes and does not take into account sources side effects.[25] Rausch *et al*. (2009) found that even in a static model the sources side effects were important in determining the distributional effects of carbon pricing. Here we repeat their counterfactual analysis in our recursive dynamic simulation.

Figure 15 provides welfare impacts across income groups for three scenarios designed to disentangle the contribution of sources and uses side effects on welfare *across* the income distribution. The logic of our counterfactual analysis is as follows. If households in different income groups are characterized by identical income shares i.e.,

[25] Sources side effects refer to burden impacts arising from changes in relative factor prices, while uses side effects refer to burden impacts arising from change in relative product prices. This terminology goes back to Musgrave (1957).

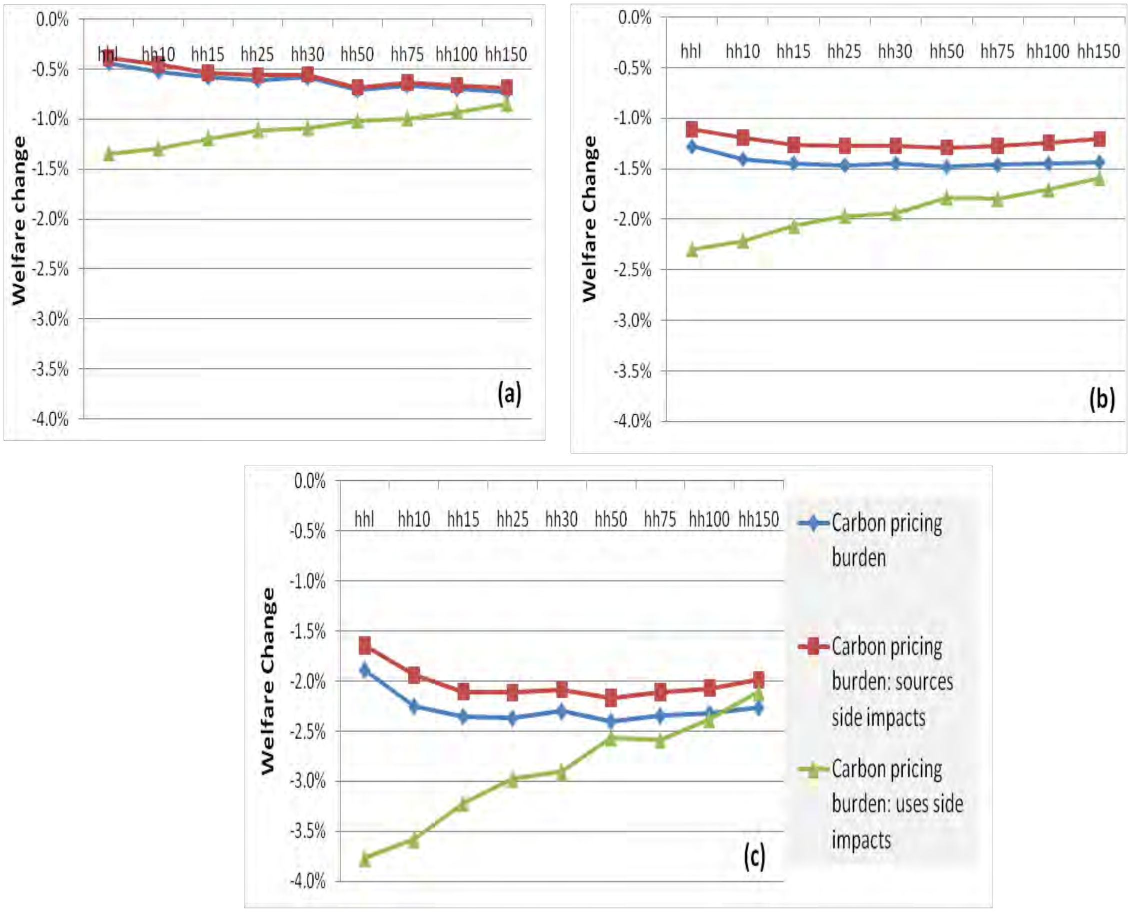

Figure 15. Relative Sources vs. Uses Side Impacts across Income Distribution: **(a)** Year 2015, **(b)** Year 2030, **(c)** Year 2050.

have equal ratios of capital, labor, and transfer income, then a change in relative factor prices affects all households equally. This counterfactual analysis isolates the distributional impacts of the uses of income effects of a policy. If households are assumed to have identical expenditure shares for all goods and services, a change in relative product prices produces an equal impact on consumers in different income classes. In that case, we isolate the distributional impacts of the sources of income effects of a policy. Any differential burden impacts of a policy across households from the counterfactual case that eliminates differences among households in how they spend their income are then determined by sources of income effects. Results that eliminate differences in income sources, allows us to focus on how uses side factors shape the relative burden of carbon pricing.

The two counterfactual cases do not eliminate these drivers of incidence but by eliminating household heterogeneity they suppress *differential* impacts across the income distribution. Harberger (1962) uses a similar analysis to identify the incidence of a corporate income tax. Note that as we measure the *real* burden, i.e., the change in

Table 8. Source of Income by Annual Income Class in USREP Model.

	Fraction of Income from Labor	Fraction of Income from Capital	Fraction of Income from Transfers	K/L ratio	Transfer / (Capital+Labor) ratio
Hhl	12.8%	6.5%	80.8%	0.5	4.2
hh10	28.6%	9.8%	61.6%	0.3	1.6
hh15	43.0%	18.2%	38.8%	0.4	0.6
hh25	48.3%	22.3%	29.5%	0.5	0.4
hh30	55.3%	24.7%	20.0%	0.4	0.3
hh50	60.4%	35.4%	4.2%	0.6	0.0
hh75	62.0%	37.5%	0.5%	0.6	0.0
hh100	59.4%	42.3%	-1.7%	0.7	0.0
hh150	57.6%	45.7%	-3.3%	0.8	0.0

Note: Based on IMPLAN data (Minnesota IMPLAN Group, 2008). Household transfers include social security, state welfare payments, unemployment compensation, veterans' benefits, food stamps, supplemental security income, direct relief, earned income credit. Note that transfers are net of household transfer payments to the rest-of-world (including cash transfers as well as goods to the rest-of-world).

equivalent variation, our incidence calculation is independent from the choice of numéraire.

Figure 15a shows results for 2015, Figure 15b for 2030 and Figure 15c for 2050. In each panel results for three cases are shown. The line labeled "carbon pricing burden" shows the welfare effect that combines income and expenditure heterogeneity. This is the welfare effect, without any recycling, given observed income sources and expenditures shares as they vary among households. The line labeled "identical income shares" eliminates heterogeneity of income sources to isolate the uses side effect of the policy. The line labeled "identical expenditure shares" eliminates expenditure heterogeneity to isolate the sources side effect. A downward slope indicates a progressive result and an upward slope a regressive result. We also show the observed burden policy impacts labeled as "carbon pricing burden." This shows the differential burden impacts resulting from heterogeneity in both the sources and uses of income.

To eliminate the muddying effect of allowance allocation we assume that the carbon revenue is not recycled to households.[26] Non-recycled revenue increases government spending on goods and services which, by assumption, is not utility enhancing. As a result, the costs to households are much larger because the allowance revenue is not available to them but we still see the striking result that carbon pricing is modestly progressive initially and, for income groups above the two lowest becomes essentially neutral by 2030. For the counterfactual analysis we hold government transfers to households constant at the no policy level.

The uses side impacts are sharply regressive in all years in accord with previous analyses that focus on expenditure side burdens only. Sources side impacts, on the

[26] We also looked at a scenario in which we assume that additional government revenue is spent according to private sector consumption. We find that this has second-order effects only.

other hand, are modestly progressive in 2015 and essentially proportional in the other years. In all years, combined effects in the line "carbon pricing burden" track closely the line "identical expenditure shares." This suggests that relative welfare impacts across the income distribution are largely driven by sources side effects.

Table 8 reports sources of income by income class for the base year, and helps to explain why sources side effects are modestly progressive especially at low income levels. The relative income burden of carbon pricing depends on the change in relative factors prices and on differences in the ratio for the sources of income for households. We find that the capital rental rate increases over time relative to the price for labor. As the capital-labor ratio slightly increases in income, just looking at the relative income burden from changes in capital and labor income would imply that the uses side is slightly regressive. This finding is in line with Fullerton and Heutel (2010) who find that the capital and labor income for the lowest income households falls proportionally more than average. What makes the source-side incidence modestly progressive to proportional is the fact that low income households derive a large fraction of income from transfers relative to low income households, and we hold transfers constant relative to the no policy baseline. Transfer income thus insulates households from changes in capital and labor income. This effect is strongest for the two lowest income households where transfers account for about 80 and 60 percent of income as shown in Table 8.[27]

Figure 15 also suggests that especially in a dynamic setting, the sources side effect is more important in determining the welfare impact than is the uses side effect for a *given* income class. The intuition for this result seems fairly obvious—over time the impacts of an ongoing mitigation policy cumulate through effects on overall economic growth and are reflected in general wage rates and capital returns. The annual abatement costs become an ever smaller share of the economic burden of the policy, and so are less important in determining the overall impacts. Furthermore, because the fraction of income derived from transfers increases over time, we find that the progressivity of the sources-side effect also slightly increases for the five lowest income groups.

Overall, this analysis demonstrates that it can be misleading to base the distributional analysis on uses side factors only. The virtue of our general equilibrium framework is the ability to capture both expenditure and income effects in a comprehensive manner.

8. SUMMARY

There has been much attention on the overall cost and efficiency of current legislative proposals for addressing climate change in the U.S. In this paper we focus on the distributional effects of the policies taking account of both the higher energy

[27] The sensitivity of distributional impacts of policies to the treatment of government transfers has been found in other work. Browning and Johnson (1979), for example, find that holding transfers fixed in real terms sharply increases the progressivity of the U.S. tax system.

costs that carbon pricing implies and the distribution of allowance value described in the bills. Secondarily we are also interested in any efficiency effects of the allowance allocation approaches in the different bills. To focus on the effect of allowance allocation, we used approximations of the allowance allocation features of current proposals, but represented here as a comparable, comprehensive cap on all emissions in the U.S. with the same level of external credits allowed across all allocation scenarios. We, therefore, did not represent other features of the bills many of which may have strong efficiency and distributional consequences. While we try to adhere to the text of the various pieces of legislation as closely as possible when allocating allowance value, we note that we had to rely on our own interpretation of legislative intent in places where allocation mechanisms were not completely defined in the bills. While the scenarios are motivated by the various proposed pieces of legislation, none of the scenarios should be interpreted as an analysis of the complete legislation.

Focusing on efficiency first, we find that retaining more of the revenue to offset the deficit impacts of the legislation, as does the Kerry Boxer bill, improves the efficiency of mitigation policy because labor and capital taxes need to be raised less to maintain revenue neutrality. Economic efficiency is improved if all deficit impacts are offset with revenue retained from the allowance auction. The trade-off is that it would leave less revenue to affect desired distributional outcomes.

We also find that the scenarios designed to approximate the Cantwell-Collins allocation proposal to be less costly than those we used to approximate the other bills. We trace this result to the fact that the Cantwell-Collins allocation proposal distributes less of the allowance value to poor households. In the other allocation schemes, more money for poorer households produces a greater income effect on energy demand, and as a result abatement is more costly. Poorer households also save less, and so more allowance value going to poor households leads to less savings and investment. Economists have widely acknowledged that there is an equity-efficiency tradeoff between schemes with lump-sum distribution and those that would cut labor and capital taxes, reducing the distortions they create. Here we find a more subtle equity-efficiency tradeoff, where even under lump sum distribution of revenue there is an efficiency gain to distributing value to wealthier households because less is spent on energy and more of the allowance value ends up as savings and investment.

Our analysis of distribution by income class and region show that the Waxman-Markey and Kerry-Boxer (or Kerry-Lieberman) allocation schemes address the distributional impacts of the policy by redistributing more of the allowance value to poorer households and to central and southern regions of the U.S. in the early years of the policy, shifting allowance value away from wealthier households and the coasts. In fact the bills redistribute to such a degree that they tend to result in net economic benefits for the poorest households and for some regions of the country such as the South Central states, Texas, and Florida that would generally be expected to bear the highest costs. The very simple per capita allocation scheme of Cantwell-Collins tends to be more distributionally neutral by income class but produces slightly less balanced outcome by region. Over time the distribution schemes matter less. In part this is because over time all these bills convert to a consumer rebate and so are more like the Cantwell-Collins allocation approach. However, over time more of the annual cost of the policy is the result of economic growth effects—reductions in past Gross Regional Product, savings, and investment. The annual abatement costs become a smaller share of the total costs, and the available revenue to alter distributional effects shrinks relative to this increasing cost.[28]

An important finding of this paper is that sources side effects of carbon mitigation proposals dominate the uses side effect in terms of determining distribution outcomes. In the near term, the distributional consequences of the carbon pricing can be significantly affected by the distribution of allowance value. Over the longer term, however, the overall growth effects are more important determinants of distribution and the revenue available from the allowance auction may not be sufficient to have much effect in changing distributional outcomes. This point is reinforced by the finding that carbon pricing by itself, i.e., when carbon revenues are not recycled back to households, is neutral to modestly progressive. This follows from the dominance of sources over uses side impacts of the policy and stands in sharp contrast to previous work that has focused only on the uses side. We find sources side effects to be modestly progressive to proportional because low income households derive a relatively large fraction of their income from transfers which insulates them from changes in capital and labor income.

We emphasize that our scenarios focused solely on the distributional implications due to carbon pricing and the allocation of allowance revenue, and that we did not attempt to model each bill in its entirety. More precise representation of the many programs described in these bills could give different outcomes and there is inevitable uncertainty in economic forecasts of this type. We also must admit significant limitations in our ability to forecast relative effects on regions over the longer term. Climate policy will dramatically change energy technologies and regions that aggressively develop these industries and attract investment could fare better even if they currently are heavily fossil energy dependent. However, such regions must overcome the initially higher costs of their fossil energy dependence.

Acknowledgments

Without implication, we would like to thank Shanta Devarajan, Denny Ellerman, Don Fullerton, one anonymous referee, and participants at the Energy Policy Symposium on Distributional Aspects of Energy and Climate Policy held in Washington, D.C., and the CEEPR Spring 2010 Workshop for helpful comments. We thank Dan Feenberg for

---

[28] As noted above, the share of allowances that must be held back for revenue neutrality in the out years falls if government spending as a share of GDP is held fixed. A priori it is not obvious which assumption on government spending is more realistic.

providing data from the NBER TAXSIM simulator on marginal income tax rates. We thank Tony Smith-Grieco for excellent research assistance. We acknowledge support of MIT Joint Program on the Science and Policy of Global Change through a combination of government, industry, and foundation funding, the MIT Energy Initiative, and additional support for this work from a coalition of industrial sponsors.

9. REFERENCES

Babiker, M., G. Metcalf and J. Reilly, 2003: Tax Distortions and Global Climate Policy. *Journal of Environmental Economics and Management*, *46*, pp. 269-87.

Babiker, M., A. Gurgel, S. Paltsev and J. Reilly, 2008: A Forward Looking Version of the MIT Emissions Prediction and Policy Analysis (EPPA) Model. MIT Joint Program on the Science and Policy of Global Change, *Report 161*, Cambridge, MA, available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt161.pdf

Ballard, C., 2000: How many hours are in a simulated day? The effect of time endowment on the results of tax-policy simulation models. Working Paper, Michigan State University.

Bento, A., L. Goulder, M. Jacobsen and R. von Haefen, 2009: Distributional and Efficiency Impacts of Increased Us Gasoline Taxes. *American Economic Review*, *99*(3), pp. 667-99.

Bovenberg, A. and L. Goulder, 2001: Neutralizing the Adverse Industry Impacts of CO_2 Abatement Policies: What Does It Cost? C. Carraro and G. E. Metcalf, *Distributional and Behavioral Effects of Environmental Policy*. Chicago: University of Chicago Press, pp. 45-85.

Bovenberg, A., L. Goulder and D. Gurney, 2005: Efficiency Costs of Meeting Industry-Distributional Constraints under Environmental Permits and Taxes. *RAND Journal of Economics*, *36*(4), pp. 951-71.

Browning, Edgar K. and William R. Johnson, 1979. *The Distribution of the Tax Burden*, Washington, DC: American Enterprise Institute.

Bull, N., K. Hassett and G. Metcalf, 1994: Who Pays Broad-Based Energy Taxes? Computing Lifetime and Regional Incidence. *Energy Journal*, *15*(3), pp. 145-64.

Burtraw, D., R. Sweeney and M. Walls, 2009: The Incidence of U.S. Climate Policy: Alternative Uses of Revenue from a Cap and Trade Auction. Washington, DC: Resources for the Future.

Burtraw, D., M. Walls and J. Blonz, 2009: Distributional Impacts of Carbon Pricing Policies in the Electricity Sector. Washington, DC: Resources For the Future.

Congressional Budget Office, 2009: The Role of the 25 Percent Revenue Offset in Estimating the Budgetary Effects of Legislation. Washington, D.C.: Congressional Budget Office.

Davies, J., F. St. Hilaire and J. Whalley, 1984: Some Calculations of Lifetime Tax Incidence. *American Economic Review*, *74*(4), pp. 633-49.

Department of Energy, 2009: U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1977 through 2007. Annual Reports, DOE/EIA-0216.

Dinan, T. and D. Rogers, 2002: Distributional Effects of Carbon Allowance Trading: How Government Decisions Determine Winners and Losers. *National Tax Journal*, *55*(2), pp. 199-221.

Dyni, J., 2006: Geology and Resources of Some World Oil-Shale Deposits. USGS Scientific Investigations Report 2005-5294, p. 42.

Energy Information Administration, 2009: Annual Energy Outlook 2009. Washington, D.C., U.S. Energy Information Administration DOE/EIA-0383.

Friedman, M., 1957: *A Theory of the Consumption Function*. Princeton, NJ: Princeton University Press.

Fullerton, D.and G. Heutel, 2007: The General Equilibrium Incidence of Environmental Taxes. *Journal of Public Economics*, *91*(3-4), pp. 571-91.

Fullerton, D.and G. Heutel, 2010: Analytical General Equilibrium Effects of Energy Policy on Output and Factor Prices. NBER Working Paper 15788, Cambridge, MA.

Fullerton, D. and D. Rogers, 1993: *Who Bears the Lifetime Tax Burden?* Washington, D.C., Brookings Institution.

Grainger, C. and C. Kolstad, 2009: Who Pays a Price on Carbon? Cambridge, MA: National Bureau of Economic Research Working Paper No. 15239.

Harberger, A., 1962: The Incidence of the Corporate Income Tax. *Journal of Political Economy 70*, pp. 215-40.

Hassett, K., A. Mathur and G. Metcalf, 2009: The Incidence of a U.S. Carbon Tax: A Lifetime and Regional Analysis. *The Energy Journal*, *30*(2), pp. 157-79.

Hyman, R., J. Reilly, M. Babiker, A. De Masin and H. Jacoby, 2003: Modeling Non-CO_2 Greenhouse Gas Abatement. *Environmental Modeling and Assessment*, *8*(3), pp. 175-86.

Lyon, A. and R. Schwab, 1995: Consumption Taxes in a Life-Cycle Framework: Are Sin Taxes Regressive? *Review of Economics and Statistics*, *77*(3), pp. 389-406.

Metcalf, G., 1999: A Distributional Analysis of Green Tax Reforms. *National Tax Journal*, *52*(4), pp. 655-81.

Metcalf, G., 2007: A Proposal for a U.S. Carbon Tax Swap: An Equitable Tax Reform to Address Global Climate Change. Washington, D.C.: The Hamilton Project, Brookings Institution.

Metcalf, G., S. Paltsev, J. Reilly, H. Jacoby and J. Holak, 2008: Analysis of a Carbon Tax to Reduce U.S. Greenhouse Gas Emissions. Cambridge, MA: MIT Joint Program on the Science and Policy of Global Change, *Report 160*, Cambridge, MA, available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt160.pdf

Minnesota IMPLAN Group, 2008: State-Level U.S. Data for 2006. Stillwater, MN: Minnesota IMPLAN Group.

Morris, J., 2009: Combining a Renewable Portfolio Standard with a Cap-and-Trade Policy: A General Equilibrium Analysis. MS in Technology and Public Policy, MIT, Cambridge, MA.

NREL, 2009: Eastern and Western Wind Datasets. Available at: http://nrel.gov/wind/integrationdatasets/

Oakridge National Laboratories, 2009: Estimated Annual Cumulative Biomass Resources Available by State and Price. Available at: http://bioenergy.ornl.gov/main.aspx#Biomass%20Resources

Paltsev, S., J. Reilly, H. Jacoby, R. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian and M. Babiker, 2005: The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4. MIT Joint Program on the Science and Policy of Global Change, *Report 125*, Cambridge, MA, available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt125.pdf

Paltsev, S., J. Reilly, H. Jacoby and J. Morris, 2009: The Cost of Climate Policy in the United States. MIT Joint Program on the Science and Policy of Global Change, *Report 173*, Cambridge, MA, available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt173.pdf

Parry, Ian W. H. 2004: Are Emissions Permits Regressive. *Journal of Environmental Economics and Management* 47:364-387.

Pechman, J., 1985: *Who Paid the Taxes: 1966-85?* Washington D.C., Brookings.

Poterba, J., 1989: Lifetime Incidence and the Distributional Burden of Excise Taxes. *American Economic Review*, *79*(2), pp. 325-30.

Poterba, J., 1991: Is the Gasoline Tax Regressive? *Tax Policy and the Economy*, *5*, pp. 145-64.

Rausch, S., G. Metcalf, J. Reilly and S. Paltsev, 2009: Distributional Impacts of a U.S. Greenhouse Gas Policy: A General Equilibrium Analysis of Carbon Pricing. MIT Joint Program on the Science and Policy of Global Change, *Report 182*, Cambridge, MA, available at: http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt182.pdf

Ross, M., 2008: Documentation of the Applied Dynamic Analysis of the Global Economy (ADAGE). Research Triangle Institute Working Paper 08-01.

Tuladhar, S., M. Yuan, P. Bernstein, W. Montgomery and A. Smith, 2009: A Top-Down Bottom-up Modeling Approach to Climate Change Policy Analysis. *Energy Economics*, *in press*.

U.S. Census Bureau, 2009a: American Community Survey 2006: Household Income in the Past 12 Months. Table B19001, accessed on 22 June 2009 via the American FactFinder website, http://factfinder.census.gov/

U.S. Census Bureau, 2009b: State Population Projections. Accessed on 11 January 2009, http://www.census.gov/population/www/projections/stproj.html

U.S. Environmental Protection Agency, 2009: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2007. Washington, D.C., Environmental Protection Agency EPA 430-R-09-004.

U.S. Geological Survey, 2009: USGS USCOAL Coal Resources Database. Available at: http://energy.er.usgs.gov/coalres.htm. and http://pubs.er.usgs.gov/djvu/B/bull_1412.djvu

REPORT SERIES of the **MIT** *Joint Program on the Science and Policy of Global Change*

1. **Uncertainty in Climate Change Policy Analysis** *Jacoby & Prinn* December 1994
2. **Description and Validation of the MIT Version of the GISS 2D Model** *Sokolov & Stone* June 1995
3. **Responses of Primary Production and Carbon Storage to Changes in Climate and Atmospheric CO_2 Concentration** *Xiao et al.* October 1995
4. **Application of the Probabilistic Collocation Method for an Uncertainty Analysis** *Webster et al.* January 1996
5. **World Energy Consumption and CO_2 Emissions: 1950-2050** *Schmalensee et al.* April 1996
6. **The MIT Emission Prediction and Policy Analysis (EPPA) Model** *Yang et al.* May 1996 (*superseded by No. 125*)
7. **Integrated Global System Model for Climate Policy Analysis** *Prinn et al.* June 1996 (*superseded by No. 124*)
8. **Relative Roles of Changes in CO_2 and Climate to Equilibrium Responses of Net Primary Production and Carbon Storage** *Xiao et al.* June 1996
9. **CO_2 Emissions Limits:** ***Economic Adjustments and the Distribution of Burdens*** *Jacoby et al.* July 1997
10. **Modeling the Emissions of N_2O and CH_4 from the Terrestrial Biosphere to the Atmosphere** *Liu* Aug. 1996
11. **Global Warming Projections:** ***Sensitivity to Deep Ocean Mixing*** *Sokolov & Stone* September 1996
12. **Net Primary Production of Ecosystems in China and its Equilibrium Responses to Climate Changes** *Xiao et al.* November 1996
13. **Greenhouse Policy Architectures and Institutions** *Schmalensee* November 1996
14. **What Does Stabilizing Greenhouse Gas Concentrations Mean?** *Jacoby et al.* November 1996
15. **Economic Assessment of CO_2 Capture and Disposal** *Eckaus et al.* December 1996
16. **What Drives Deforestation in the Brazilian Amazon?** *Pfaff* December 1996
17. **A Flexible Climate Model For Use In Integrated Assessments** *Sokolov & Stone* March 1997
18. **Transient Climate Change and Potential Croplands of the World in the 21st Century** *Xiao et al.* May 1997
19. **Joint Implementation:** ***Lessons from Title IV's Voluntary Compliance Programs*** *Atkeson* June 1997
20. **Parameterization of Urban Subgrid Scale Processes in Global Atm. Chemistry Models** *Calbo* et al. July 1997
21. **Needed: A Realistic Strategy for Global Warming** *Jacoby, Prinn & Schmalensee* August 1997
22. **Same Science, Differing Policies;** ***The Saga of Global Climate Change*** *Skolnikoff* August 1997
23. **Uncertainty in the Oceanic Heat and Carbon Uptake and their Impact on Climate Projections** *Sokolov et al.* September 1997
24. **A Global Interactive Chemistry and Climate Model** *Wang, Prinn & Sokolov* September 1997
25. **Interactions Among Emissions, Atmospheric Chemistry & Climate Change** *Wang & Prinn* Sept. 1997
26. **Necessary Conditions for Stabilization Agreements** *Yang & Jacoby* October 1997
27. **Annex I Differentiation Proposals:** ***Implications for Welfare, Equity and Policy*** *Reiner & Jacoby* Oct. 1997
28. **Transient Climate Change and Net Ecosystem Production of the Terrestrial Biosphere** *Xiao et al.* November 1997
29. **Analysis of CO_2 Emissions from Fossil Fuel in Korea: 1961–1994** *Choi* November 1997
30. **Uncertainty in Future Carbon Emissions:** ***A Preliminary Exploration*** *Webster* November 1997
31. **Beyond Emissions Paths:** ***Rethinking the Climate Impacts of Emissions Protocols*** *Webster & Reiner* November 1997
32. **Kyoto's Unfinished Business** *Jacoby et al.* June 1998
33. **Economic Development and the Structure of the Demand for Commercial Energy** *Judson et al.* April 1998
34. **Combined Effects of Anthropogenic Emissions and Resultant Climatic Changes on Atmospheric OH** *Wang & Prinn* April 1998
35. **Impact of Emissions, Chemistry, and Climate on Atmospheric Carbon Monoxide** *Wang & Prinn* April 1998
36. **Integrated Global System Model for Climate Policy Assessment:** ***Feedbacks and Sensitivity Studies*** *Prinn et al.* June 1998
37. **Quantifying the Uncertainty in Climate Predictions** *Webster & Sokolov* July 1998
38. **Sequential Climate Decisions Under Uncertainty:** ***An Integrated Framework*** *Valverde et al.* September 1998
39. **Uncertainty in Atmospheric CO_2 (Ocean Carbon Cycle Model Analysis)** *Holian* Oct. 1998 (*superseded by No. 80*)
40. **Analysis of Post-Kyoto CO_2 Emissions Trading Using Marginal Abatement Curves** *Ellerman & Decaux* Oct. 1998
41. **The Effects on Developing Countries of the Kyoto Protocol and CO_2 Emissions Trading** *Ellerman et al.* November 1998
42. **Obstacles to Global CO_2 Trading:** ***A Familiar Problem*** *Ellerman* November 1998
43. **The Uses and Misuses of Technology Development as a Component of Climate Policy** *Jacoby* November 1998
44. **Primary Aluminum Production:** ***Climate Policy, Emissions and Costs*** *Harnisch et al.* December 1998
45. **Multi-Gas Assessment of the Kyoto Protocol** *Reilly et al.* January 1999
46. **From Science to Policy:** ***The Science-Related Politics of Climate Change Policy in the U.S.*** *Skolnikoff* January 1999
47. **Constraining Uncertainties in Climate Models Using Climate Change Detection Techniques** *Forest et al.* April 1999
48. **Adjusting to Policy Expectations in Climate Change Modeling** *Shackley et al.* May 1999
49. **Toward a Useful Architecture for Climate Change Negotiations** *Jacoby et al.* May 1999
50. **A Study of the Effects of Natural Fertility, Weather and Productive Inputs in Chinese Agriculture** *Eckaus & Tso* July 1999
51. **Japanese Nuclear Power and the Kyoto Agreement** *Babiker, Reilly & Ellerman* August 1999
52. **Interactive Chemistry and Climate Models in Global Change Studies** *Wang & Prinn* September 1999
53. **Developing Country Effects of Kyoto-Type Emissions Restrictions** *Babiker & Jacoby* October 1999

Contact the Joint Program Office to request a copy. The Report Series is distributed at no charge.

54. **Model Estimates of the Mass Balance of the Greenland and Antarctic Ice Sheets** *Bugnion* Oct 1999
55. **Changes in Sea-Level Associated with Modifications of Ice Sheets over 21st Century** *Bugnion* October 1999
56. **The Kyoto Protocol and Developing Countries** *Babiker et al.* October 1999
57. **Can EPA Regulate Greenhouse Gases Before the Senate Ratifies the Kyoto Protocol?** *Bugnion & Reiner* November 1999
58. **Multiple Gas Control Under the Kyoto Agreement** *Reilly, Mayer & Harnisch* March 2000
59. **Supplementarity:** ***An Invitation for Monopsony?*** *Ellerman & Sue Wing* April 2000
60. **A Coupled Atmosphere-Ocean Model of Intermediate Complexity** *Kamenkovich et al.* May 2000
61. **Effects of Differentiating Climate Policy by Sector:** ***A U.S. Example*** *Babiker et al.* May 2000
62. **Constraining Climate Model Properties Using Optimal Fingerprint Detection Methods** *Forest et al.* May 2000
63. **Linking Local Air Pollution to Global Chemistry and Climate** *Mayer et al.* June 2000
64. **The Effects of Changing Consumption Patterns on the Costs of Emission Restrictions** *Lahiri et al.* Aug 2000
65. **Rethinking the Kyoto Emissions Targets** *Babiker & Eckaus* August 2000
66. **Fair Trade and Harmonization of Climate Change Policies in Europe** *Viguier* September 2000
67. **The Curious Role of "Learning" in Climate Policy:** ***Should We Wait for More Data?*** *Webster* October 2000
68. **How to Think About Human Influence on Climate** *Forest, Stone & Jacoby* October 2000
69. **Tradable Permits for Greenhouse Gas Emissions:** ***A primer with reference to Europe*** *Ellerman* Nov 2000
70. **Carbon Emissions and The Kyoto Commitment in the European Union** *Viguier et al.* February 2001
71. **The MIT Emissions Prediction and Policy Analysis Model:** ***Revisions, Sensitivities and Results*** *Babiker et al.* February 2001 (*superseded by No. 125*)
72. **Cap and Trade Policies in the Presence of Monopoly and Distortionary Taxation** *Fullerton & Metcalf* March '01
73. **Uncertainty Analysis of Global Climate Change Projections** *Webster et al.* Mar. '01 (*superseded by No. 95*)
74. **The Welfare Costs of Hybrid Carbon Policies in the European Union** *Babiker et al.* June 2001
75. **Feedbacks Affecting the Response of the Thermohaline Circulation to Increasing CO_2** *Kamenkovich et al.* July 2001
76. **CO_2 Abatement by Multi-fueled Electric Utilities:** ***An Analysis Based on Japanese Data*** *Ellerman & Tsukada* July 2001
77. **Comparing Greenhouse Gases** *Reilly et al.* July 2001
78. **Quantifying Uncertainties in Climate System Properties using Recent Climate Observations** *Forest et al.* July 2001
79. **Uncertainty in Emissions Projections for Climate Models** *Webster et al.* August 2001
80. **Uncertainty in Atmospheric CO_2 Predictions from a Global Ocean Carbon Cycle Model** *Holian et al.* September 2001
81. **A Comparison of the Behavior of AO GCMs in Transient Climate Change Experiments** *Sokolov et al.* December 2001
82. **The Evolution of a Climate Regime:** ***Kyoto to Marrakech*** *Babiker, Jacoby & Reiner* February 2002
83. **The "Safety Valve" and Climate Policy** *Jacoby & Ellerman* February 2002
84. **A Modeling Study on the Climate Impacts of Black Carbon Aerosols** *Wang* March 2002
85. **Tax Distortions and Global Climate Policy** *Babiker et al.* May 2002
86. **Incentive-based Approaches for Mitigating Greenhouse Gas Emissions:** ***Issues and Prospects for India*** *Gupta* June 2002
87. **Deep-Ocean Heat Uptake in an Ocean GCM with Idealized Geometry** *Huang, Stone & Hill* September 2002
88. **The Deep-Ocean Heat Uptake in Transient Climate Change** *Huang et al.* September 2002
89. **Representing Energy Technologies in Top-down Economic Models using Bottom-up Information** *McFarland et al.* October 2002
90. **Ozone Effects on Net Primary Production and Carbon Sequestration in the U.S. Using a Biogeochemistry Model** *Felzer et al.* November 2002
91. **Exclusionary Manipulation of Carbon Permit Markets:** ***A Laboratory Test*** *Carlén* November 2002
92. **An Issue of Permanence:** ***Assessing the Effectiveness of Temporary Carbon Storage*** *Herzog et al.* December 2002
93. **Is International Emissions Trading Always Beneficial?** *Babiker et al.* December 2002
94. **Modeling Non-CO_2 Greenhouse Gas Abatement** *Hyman et al.* December 2002
95. **Uncertainty Analysis of Climate Change and Policy Response** *Webster et al.* December 2002
96. **Market Power in International Carbon Emissions Trading:** ***A Laboratory Test*** *Carlén* January 2003
97. **Emissions Trading to Reduce Greenhouse Gas Emissions in the United States:** ***The McCain-Lieberman Proposal*** *Paltsev et al.* June 2003
98. **Russia's Role in the Kyoto Protocol** *Bernard et al.* Jun '03
99. **Thermohaline Circulation Stability:** ***A Box Model Study*** *Lucarini & Stone* June 2003
100. **Absolute vs. Intensity-Based Emissions Caps** *Ellerman & Sue Wing* July 2003
101. **Technology Detail in a Multi-Sector CGE Model:** ***Transport Under Climate Policy*** *Schafer & Jacoby* July 2003
102. **Induced Technical Change and the Cost of Climate Policy** *Sue Wing* September 2003
103. **Past and Future Effects of Ozone on Net Primary Production and Carbon Sequestration Using a Global Biogeochemical Model** *Felzer et al.* (revised) January 2004
104. **A Modeling Analysis of Methane Exchanges Between Alaskan Ecosystems and the Atmosphere** *Zhuang et al.* November 2003

Contact the Joint Program Office to request a copy. The Report Series is distributed at no charge.

105. Analysis of Strategies of Companies under Carbon Constraint *Hashimoto* January 2004
106. Climate Prediction: ***The Limits of Ocean Models*** *Stone* February 2004
107. Informing Climate Policy Given Incommensurable Benefits Estimates *Jacoby* February 2004
108. Methane Fluxes Between Terrestrial Ecosystems and the Atmosphere at High Latitudes During the Past Century *Zhuang et al.* March 2004
109. Sensitivity of Climate to Diapycnal Diffusivity in the Ocean *Dalan et al.* May 2004
110. Stabilization and Global Climate Policy *Sarofim et al.* July 2004
111. Technology and Technical Change in the MIT EPPA Model *Jacoby et al.* July 2004
112. The Cost of Kyoto Protocol Targets: ***The Case of Japan*** *Paltsev et al.* July 2004
113. Economic Benefits of Air Pollution Regulation in the USA: ***An Integrated Approach*** *Yang et al.* (revised) Jan. 2005
114. The Role of Non-CO_2 Greenhouse Gases in Climate Policy: ***Analysis Using the MIT IGSM*** *Reilly et al.* Aug. '04
115. Future U.S. Energy Security Concerns *Deutch* Sep. '04
116. Explaining Long-Run Changes in the Energy Intensity of the U.S. Economy *Sue Wing* Sept. 2004
117. Modeling the Transport Sector: ***The Role of Existing Fuel Taxes in Climate Policy*** *Paltsev et al.* November 2004
118. Effects of Air Pollution Control on Climate *Prinn et al.* January 2005
119. Does Model Sensitivity to Changes in CO_2 Provide a Measure of Sensitivity to the Forcing of Different Nature? *Sokolov* March 2005
120. What Should the Government Do To Encourage Technical Change in the Energy Sector? *Deutch* May '05
121. Climate Change Taxes and Energy Efficiency in Japan *Kasahara et al.* May 2005
122. A 3D Ocean-Seaice-Carbon Cycle Model and its Coupling to a 2D Atmospheric Model: ***Uses in Climate Change Studies*** *Dutkiewicz et al.* (revised) November 2005
123. Simulating the Spatial Distribution of Population and Emissions to 2100 *Asadoorian* May 2005
124. MIT Integrated Global System Model (IGSM) Version 2: ***Model Description and Baseline Evaluation*** *Sokolov et al.* July 2005
125. The MIT Emissions Prediction and Policy Analysis (EPPA) Model: ***Version 4*** *Paltsev et al.* August 2005
126. Estimated PDFs of Climate System Properties Including Natural and Anthropogenic Forcings *Forest et al.* September 2005
127. An Analysis of the European Emission Trading Scheme *Reilly & Paltsev* October 2005
128. Evaluating the Use of Ocean Models of Different Complexity in Climate Change Studies *Sokolov et al.* November 2005
129. ***Future*** **Carbon Regulations and** ***Current*** **Investments in Alternative Coal-Fired Power Plant Designs** *Sekar et al.* December 2005
130. Absolute vs. Intensity Limits for CO_2 Emission Control: ***Performance Under Uncertainty*** *Sue Wing et al.* January 2006
131. The Economic Impacts of Climate Change: ***Evidence from Agricultural Profits and Random Fluctuations in Weather*** *Deschenes & Greenstone* January 2006
132. The Value of Emissions Trading *Webster et al.* Feb. 2006
133. Estimating Probability Distributions from Complex Models with Bifurcations: ***The Case of Ocean Circulation Collapse*** *Webster et al.* March 2006
134. Directed Technical Change and Climate Policy *Otto et al.* April 2006
135. Modeling Climate Feedbacks to Energy Demand: ***The Case of China*** *Asadoorian et al.* June 2006
136. Bringing Transportation into a Cap-and-Trade Regime *Ellerman, Jacoby & Zimmerman* June 2006
137. Unemployment Effects of Climate Policy *Babiker & Eckaus* July 2006
138. Energy Conservation in the United States: ***Understanding its Role in Climate Policy*** *Metcalf* Aug. '06
139. Directed Technical Change and the Adoption of CO_2 Abatement Technology: ***The Case of CO_2 Capture and Storage*** *Otto & Reilly* August 2006
140. The Allocation of European Union Allowances: ***Lessons, Unifying Themes and General Principles*** *Buchner et al.* October 2006
141. Over-Allocation or Abatement? ***A preliminary analysis of the EU ETS based on the 2006 emissions data*** *Ellerman & Buchner* December 2006
142. Federal Tax Policy Towards Energy *Metcalf* Jan. 2007
143. Technical Change, Investment and Energy Intensity *Kratena* March 2007
144. Heavier Crude, Changing Demand for Petroleum Fuels, Regional Climate Policy, and the Location of Upgrading Capacity *Reilly et al.* April 2007
145. Biomass Energy and Competition for Land *Reilly & Paltsev* April 2007
146. Assessment of U.S. Cap-and-Trade Proposals *Paltsev et al.* April 2007
147. A Global Land System Framework for Integrated Climate-Change Assessments *Schlosser et al.* May 2007
148. Relative Roles of Climate Sensitivity and Forcing in Defining the Ocean Circulation Response to Climate Change *Scott et al.* May 2007
149. Global Economic Effects of Changes in Crops, Pasture, and Forests due to Changing Climate, CO_2 and Ozone *Reilly et al.* May 2007
150. U.S. GHG Cap-and-Trade Proposals: ***Application of a Forward-Looking Computable General Equilibrium Model*** *Gurgel et al.* June 2007
151. Consequences of Considering Carbon/Nitrogen Interactions on the Feedbacks between Climate and the Terrestrial Carbon Cycle *Sokolov et al.* June 2007
152. Energy Scenarios for East Asia: 2005-2025 *Paltsev & Reilly* July 2007
153. Climate Change, Mortality, and Adaptation: ***Evidence from Annual Fluctuations in Weather in the U.S.*** *Deschênes & Greenstone* August 2007

Contact the Joint Program Office to request a copy. The Report Series is distributed at no charge.

154. Modeling the Prospects for Hydrogen Powered Transportation Through 2100 *Sandoval et al.* February 2008
155. Potential Land Use Implications of a Global Biofuels Industry *Gurgel et al.* March 2008
156. Estimating the Economic Cost of Sea-Level Rise *Sugiyama et al.* April 2008
157. Constraining Climate Model Parameters from Observed 20th Century Changes *Forest et al.* April 2008
158. Analysis of the Coal Sector under Carbon Constraints *McFarland et al.* April 2008
159. Impact of Sulfur and Carbonaceous Emissions from International Shipping on Aerosol Distributions and Direct Radiative Forcing *Wang & Kim* April 2008
160. Analysis of U.S. Greenhouse Gas Tax Proposals *Metcalf et al.* April 2008
161. A Forward Looking Version of the MIT Emissions Prediction and Policy Analysis (EPPA) Model *Babiker et al.* May 2008
162. The European Carbon Market in Action: ***Lessons from the first trading period*** Interim Report *Convery, Ellerman, & de Perthuis* June 2008
163. The Influence on Climate Change of Differing Scenarios for Future Development Analyzed Using the MIT Integrated Global System Model *Prinn et al.* September 2008
164. Marginal Abatement Costs and Marginal Welfare Costs for Greenhouse Gas Emissions Reductions: ***Results from the EPPA Model*** *Holak et al.* November 2008
165. Uncertainty in Greenhouse Emissions and Costs of Atmospheric Stabilization *Webster et al.* November 2008
166. Sensitivity of Climate Change Projections to Uncertainties in the Estimates of Observed Changes in Deep-Ocean Heat Content *Sokolov et al.* November 2008
167. Sharing the Burden of GHG Reductions *Jacoby et al.* November 2008
168. Unintended Environmental Consequences of a Global Biofuels Program *Melillo et al.* January 2009
169. Probabilistic Forecast for 21st Century Climate Based on Uncertainties in Emissions (without Policy) and Climate Parameters *Sokolov et al.* January 2009
170. The EU's Emissions Trading Scheme: ***A Proto-type Global System?*** *Ellerman* February 2009
171. Designing a U.S. Market for CO_2 *Parsons et al.* February 2009
172. Prospects for Plug-in Hybrid Electric Vehicles in the United States & Japan: ***A General Equilibrium Analysis*** *Karplus et al.* April 2009
173. The Cost of Climate Policy in the United States *Paltsev et al.* April 2009
174. A Semi-Empirical Representation of the Temporal Variation of Total Greenhouse Gas Levels Expressed as Equivalent Levels of Carbon Dioxide *Huang et al.* June 2009
175. Potential Climatic Impacts and Reliability of Very Large Scale Wind Farms *Wang & Prinn* June 2009
176. Biofuels, Climate Policy and the European Vehicle Fleet *Gitiaux et al.* August 2009
177. Global Health and Economic Impacts of Future Ozone Pollution *Selin et al.* August 2009
178. Measuring Welfare Loss Caused by Air Pollution in Europe: ***A CGE Analysis*** *Nam et al.* August 2009
179. Assessing Evapotranspiration Estimates from the Global Soil Wetness Project Phase 2 (GSWP-2) Simulations *Schlosser and Gao* September 2009
180. Analysis of Climate Policy Targets under Uncertainty *Webster et al.* September 2009
181. Development of a Fast and Detailed Model of Urban-Scale Chemical and Physical Processing *Cohen & Prinn* October 2009
182. Distributional Impacts of a U.S. Greenhouse Gas Policy: ***A General Equilibrium Analysis of Carbon Pricing*** *Rausch et al.* November 2009
183. Canada's Bitumen Industry Under CO_2 Constraints *Chan et al.* January 2010
184. Will Border Carbon Adjustments Work? *Winchester et al.* February 2010
185. Distributional Implications of Alternative U.S. Greenhouse Gas Control Measures *Rausch et al.* June 2010