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The Cost of Climate Regulation for American Households

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Executive Summary

In this paper we summarize various estimates of the costs of mitigation of adverse impact of the climate change via cap-and-trade. We find that the differences in the estimated impacts on gross domestic product (GDP), consumption, employment, and gasoline, electricity and natural gas prices are mainly driven by the following factors: the timeframe of new technology development, growth potential of existing clean sources of energy, availability of offsets (domestic, and international), and banking of allowances.

However, our main finding is that even for more optimistic estimates, the mitigation costs are likely to amount to as much as 1% drop in consumption starting today and going into the future, which, as we argue, constitutes an enormous impact on social welfare. Thus, it is important to carefully assess the costs of global warming to see whether they justify such drastic measures.

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I. Introduction

There is a growing body of literature which tries to assess the costs of climate change and propose ways to mitigate its negative impacts.[1] The Democratic and Republican candidates in the 2008 U.S. president election both favored a comprehensive regulatory regime to mitigate the adverse impacts of climate change. The winning candidate, President Barack Obama, supports the implementation of a market-based cap-and-trade system to reduce carbon emissions by the amount many scientists say is necessary: 80 percent below 1990 levels by 2050.[2]

It appears likely that some form of cap-and-trade system to cut greenhouse-gas (GHG) emissions will be enacted in the U.S. in the coming years. Thus, it is important for the public to fully understand both the costs of climate change and the costs of avoiding its negative impacts. While the media, policymakers, and others have given much attention to the possible negative impacts of the climate change, comparatively little effort has been devoted to presenting the cost estimates of differing mitigation strategies. American households will bear large costs if any of the proposed plans to curb GHG emissions are adopted.

In the present paper we summarize many of the available household-level mitigation cost estimates. We compare these estimates to gauge their relative sensitivities to differing assumptions. These assumptions include, but are not limited to, educated guesses about the level and timing of proposed abatement efforts, the costs and timeframe of developing new and cleaner technologies or improving existing ones, and mitigation efforts on part of other countries.

In particular, we summarize different cost estimates generated for the Lieberman-Warner Climate Security Act (S.2191) and discuss other legislative proposals such as the Low Carbon Economy Act (S.1766) and carbon tax proposals proffered by Representatives Dingell, Stark, and others. Yet our main focus is Lieberman-Warner, since its provisions most closely resemble the vision put forth by President Obama. Moreover, many have argued a carbon tax system is not a politically viable option for the foreseeable future.

The rest of the paper is organized as follows: Section II compares the results and assumptions of the seven cost-estimate analyses conducted upon Lieberman-Warner. Section III discusses Lieberman-Warner in more depth and summarizes the individual cost-estimate analyses we investigated. Section IV discusses estimates of other abatement proposals. Section V concludes our analysis.

II. Main Findings

We analyzed seven analyses of Lieberman-Warner focusing on the cost aspects which we think are of particular importance to American households: change in GDP and resulting change in household consumption, employment changes, and increases in gasoline, natural gas, and electricity prices. The following groups and organizations conducted these studies:

1. MIT Joint Program on the Science and Policy of Global Change
2. The American Council for Capital Formation (ACCF) and the National Association of Manufacturers (NAM)
3. CRA International
4. The Environmental Protection Agency
5. The Energy Information Administration (EIA)
6. The Heritage Foundation's Center for Data Analysis (CDA)
7. The Clean Air Task Force (CATF)

Impact on GDP

Estimated GDP losses vary widely, from a 0.3%-0.5% to 3% drop in GDP below the business-as-usual projections in 2015 and a 1% to 10% drop in 2050. The timeframes of new technology development and growth in existing clean sources of energy, availability of offsets (domestic, international), and banking of allowances are likely to account for most of these differences in GDP costs estimates.

The studies listed above make different modeling assumptions about the abatement process; hence, the resulting estimates of GDP losses vary considerably. Table 1 shows the estimated impact on GDP from the seven studies under consideration. The MIT group, EIA, and CATF predict comparatively lower damage to GDP (around 0.5% in 2015 and 2030 going up to 1% in 2050); the CRA and ACCF estimates are much higher at 1% on average in 2015 up to 3% in 2030. The CDA and EPA estimates fall somewhere in between these extremes.

A comparative analysis of both the models' assumptions and results reveals that the following three factors are likely to account for the differences in the estimated impact on GDP:

- The timeframe of the development of cleaner sources of energy[3] and growth potential of nuclear and renewable sources of energy,
- The availability of offsets (domestic and/or international), and
- The banking of allowances

Table 2 compares the seven models' assumptions regarding these three factors. Summaries that include more information about the assumptions are available in the Appendix, and Section III provides more detailed information about individual models.

Studies assuming a limited availability of alternative sources of energy or slower development and adoption of carbon-free sources of energy predict higher GDP losses. This is quite understandable, since hitting the same abatement target with "dirtier" sources of energy requires greater cutbacks in energy consumption and results in higher GDP loss. GDP could decrease by a factor of two to three, depending on alternative assumptions.

For example, the ACCF/NAM analysis caps some alternative energy source development and deployment such as wind, biomass and clean coal and natural gas carbon capture and sequestration (CCS) technologies. In turn, the estimated costs reported by ACCF are considerably higher than for alternative studies examining scenarios without these alternative energy caps. On the other hand, the CATF study uses the same NEMS model as ACCF, but without such severe constraints on new mitigation technology development, and consequently arrives at much lower GDP loss estimates.

Many other studies include scenarios with different assumptions about the potential growth of alternative energy sources. Different scenarios presuming strong constraints on renewables, nuclear and other forms of cleaner energy development arrive at larger cost estimates. For example, the EPA tested a scenario with constrained nuclear, biomass and carbon capture and storage, which predicted GDP losses of 1.5 to 2 times higher than the EPA scenarios lacking such technological constraints. Similar effects are observed in other studies as well.

Table 1: Percent Change in GDP from Baseline

Group	Model	Scenario	% Change in GDP from Baseline 2015	% Change in GDP from Baseline 2030	% Change in GDP from Baseline 2050
MIT	EPPA	No Offsets, No CSS Subsidy	-0.65%	-0.31%	-1.10%
		15% Offsets	-0.55%	-0.54%	-0.82%
		CSS Subsidy	-0.66%	-0.26%	-1.01%
		15% Offsets, CSS Subsidy	-0.57%	-0.38%	-0.75%
ACCF/NAM*	NEMS	Low Cost	-0.80%	-2.60%	NA
		High Cost	-1.20%	-2.40%	NA
CRA	MRN-NEEM	S. 2191	-1.75%	-1.00%	-3.50%
CDA*	GI	Generous	-0.14%	-0.56%	NA
		Reasonable	-1.02%	-2.18%	NA
EPA	ADAGE	S. 2191	-0.70%	-0.90%	-2.37%
	IGEM		-2.00%	-3.76%	-6.90%
	ADAGE	S. 2191- No Offsets	NA	NA	NA
	IGEM		-3.30%	-5.90%	-10.10%
	ADAGE	S. 2191- Constrained Nuclear, Biomass and CCS	-1.10%	-2.30%	-4.40%
	IGEM		NA	NA	NA
EIA**	NEMS	S. 2191 Core	-0.30%	-0.30%	NA
		S. 2191 Limited Alternative/ No International Offsets	-0.90%	-0.80%	NA
CATF	NEMS	S. 2191	NA	-0.70%	NA

* ACCF/NAM reports in the year 2014.
**EIA reports in the year 2020.

Table 2: Assumptions of the Models

Group	Scenario	Limited alternatives	Availability of Offsets	Banking of Allowances
MIT	No Offsets, No CSS Subsidy	Yes	No	Yes
	15% Offsets	Yes	Limited	Yes
	CSS Subsidy	No	No	Yes
	15% Offsets, CSS Subsidy	No	Limited	Yes
ACCF/NAM*	Low Cost	Somewhat limited	Somewhat limited	No
	High Cost	Yes	Limited	No
CRA	S. 2191	No	Yes	Yes
CDA*	Generous	Somewhat limited	Yes	No
	Reasonable	Yes	Yes	No
EPA	S. 2191	No	Yes	Yes
	S. 2191 - No Offsets	No	No	Yes
	Constrained Nuclear, Biomass, CCS	Yes	Yes	Yes
EIA**	S. 2191 Core	No	Yes	Yes
	S. 2191 Limited Alternative/No International Offsets	Yes	No	Yes
CATF	S. 2191	No	Yes	Yes

* ACCF/NAM reports in the year 2014.
**EIA reports in the year 2020.

Entities covered by Lieberman-Warner can satisfy their GHG reduction obligations by either purchasing carbon allowances or engaging in other projects which will offset their obligation. Firms can purchase offsets from international cap-and-trade programs similar to the one envisioned by Lieberman-Warner or they can engage in emission reduction for non-covered emission types, which lowers their obligation on the covered emissions.

This essentially gives firms additional opportunities to satisfy emission caps, and, thus, leads to lower costs of abatement. When no offsets are assumed, estimated costs go up in all models by (approximately) a factor of 1.5.

The second major factor affecting mitigation cost estimates is the availability of domestic/international GHG offsets. Entities covered by Lieberman-Warner can satisfy part of their GHG reduction obligations by either purchasing carbon allowances or engaging in other projects offsetting some of their contributions. Firms can purchase offsets from international cap-and-trade programs similar to the one envisioned by Lieberman-Warner. When no offsets are assumed, estimated costs increase in all models. Greater availability of offsetting options reduces the economic impacts of Lieberman-Warner. In the EPA model, the absence of international offsets increases estimated costs by a factor of 1.5, from 2% in 2015 to 3% in 2015 (using the IGEM model). The ACCF/NAM study assumes limited amounts of offsets (<20%) in the "high cost scenario," which increases the estimated cost by a factor of 1.5 compared to the case where there is no such restriction on offsets.

The third factor significantly influencing estimated costs is availability of "banking" allowances. Banking enables firms to save unused allowances for later years, essentially providing firms the flexibility to gradually adjust their operations to meet the targets and lessen the overall abatement costs. When the permissibility of banking is assumed, estimated costs fall by a factor of 2.

Finally, the ability to "bank" or store allowances also has a major impact on the estimated costs of abatement. Allowance banking allows covered entities to save credits they do not use or sell in a given year. Saving credits provides these entities more flexibility when the total number of credits begins to decline in future years. If firms are given the opportunity to store credits, then they can gradually adjust their operations to meet targets, lessen their overall abatement costs and "cushion the blow" of declining emissions. For example, the CRA study provides cost estimates with and without the banking assumption. When banking is permitted, the entire costs of programs such as those proposed by Lieberman-Warner are significantly decreased.

Studies assuming that no banking of allowances is permitted usually show higher estimates of loss in GDP: for example, the ACCF/NAM, CRA, and CDA scenarios which do not include banking estimate GDP losses 1.5-2 times higher than other models which include banking of allowances, such as the EIA and MIT studies.

Impact on Consumption and Social Welfare

Consumption is predominantly affected by the same factors as GDP. As before, studies which assume limited alternative sources of energy and/or limited offsets usually show higher (by a factor of 2 or 3) consumption cost estimates.

GDP is not the most informative measure of a GHG mitigation plan's household impact. Measuring changes in consumption is a better way of determining the burdens that individual American households will bear under cap-and-trade through examining the welfare losses. While individual utility/welfare is not directly observable, measuring household consumption is undoubtedly a more direct gauge of household well-being than GDP. Table 3 presents estimated drops in consumption in response to the mitigation path consistent with Lieberman-Warner in 2015, 2030 and 2050.

A comparison of Table 3's results to those of Table 1, shows the expected GDP/consumption correlation: studies that estimate higher drops in GDP are likely to have higher estimated drops in consumption as well. Thus, the assumptions affecting GDP loss (availability of offsets, the timeframe of low-carbon technology development, and predictions about the growth of existing sources of clean and renewable energy) also alter the magnitude of decreases in consumption.

Table 3: Percent Change in Consumption from Baseline

Group	Scenario	% Change in 2015	% Change in 2030	% Change in 2050	Balanced Growth Equivalent***	Reported Impact
MIT	No Offsets, No CSS Subsidy	-0.35%	-1.93%	-2.36%	-0.96%	Change in Market Consumption
	15% Offsets	-0.29%	-1.60%	-2.10%	-0.81%	
	CSS Subsidy	-0.37%	-1.93%	-2.26%	-0.97%	
	15% Offsets, CSS Subsidy	-0.31%	-1.47%	-2.01%	-0.77%	
ACCF/NAM*	Low Cost	-1.00%	-2.90%	NA	-0.98% (-1.57%)	Change in Household Income
	High Cost	-2.80%	-4.90%	NA	-2.57% (-3.09%)	
CRA		-4.50%	-3.50%	-4.20%	-3.17%	Cost Per Household
CDA*	Generous	-0.60%	-0.48%	NA	-0.41% (-0.42%)	Change in Personal Consumption
	Reasonable	-1.35%	-0.94%	NA	-0.89% (-0.90%)	
EPA**	S2191: ADAGE	-0.43%	-0.91%	-2.10%	-0.65%	Change in Market Consumption
	S.2191: IGEM	-0.66%	-1.44%	-3.26%	-1.02%	
EIA**	S. 2191 Core	-0.40%	-0.50%	NA	-0.31% (-0.36%)	Change in Market Consumption
	S. 2191 Limited Alternatives/ No International Offsets	-1.20%	-1.10%	NA	-0.86% (-0.91%)	
CATF	S. 2191	NA	-0.90%	NA	NA	Change in Per Capita GDP

* ACCF/NAM reports in the year 2014.
**EIA reports in the year 2020.
*** Estimates in brackets are computed for studies with "NA" in 2050 on the assumption that damages in 2050 equal to damages in 2030

Studies assuming limited alternative sources of energy and/or limited offsets usually result in higher consumption cost estimates. The ACCF study, which puts caps on development of nuclear and alternative energy sources, predicts a decline in consumption that is two to three times higher than the MIT, EPA or EIA results, which do not make such restrictions. Moreover, one ACCF scenario that both tightens caps on renewable energy development and strictly limits the availability of offsets (the "high cost" scenario) estimates consumption losses increase by a factor of 2.8. Similarly, one EIA study scenario estimates consumption losses increase by a factor of 2 to 3 when assuming limited alternatives to coal-generated energy production and no international offsetting opportunities for U.S. firms.

Even under the most optimistic assumptions, *every* study we examined predicts huge welfare costs in terms of consumption. A lower estimate involves a drop in consumption of 0.8%-1% below the business-as-usual scenario in *every year* starting in 2008 and going into the future, which represents a huge decrease in social welfare.

Our examination of the costs to consumption permits us to more closely evaluate Lieberman-Warner's impact on overall social welfare. In particular we answer the following questions: How large are the estimated drops in consumption? What does a 1% decrease in consumption in 2015 or a 3% drop in 2050 mean for the average American household today when our leaders are considering making major policy decisions?

We measure the impact on individual household well-being (following Lucas 1990) in terms of balanced growth equivalency. In order to calculate the balanced growth equivalent, we assume that consumption grows at a constant rate under the business-as-usual scenario. The effects of mitigation efforts required by a cap-and-trade system cause consumption to drop below this constant path. Table 3 presents data estimating decreases in consumption in 2015, 2030, and 2030. When computing the balanced growth equivalent, we assume that consumption is growing at the same rate as under the business-as-usual scenario, but its level is permanently below the business-as-usual path by some percentage. We choose a particular percentage so that individual well-being under the balanced growth equivalent is the same as under a mitigation path. We report this percentage in Table 3 as well.

Our calculations suggest that consumption under the constraints posed by Lieberman-Warner's cap-and-trade regime is equivalent to a constant (in percentage terms) consumption decrease of around 0.8%-1% each year, starting today and continuing to 2050.

At first glance, a consumption decrease of one percent may appear trivial. However, as the 1% per year decreases compound, the welfare losses are substantial in the aggregate. This phenomenon is familiar to long-term investors. Small initial investments accruing modest returns over a long period of time result in large overall increases. It is worth remembering what Nobel laureate Robert Lucas said concerning the estimated the welfare gains from elimination of capital income taxation, which he calculated to be around 1 percent of consumption:

> "…I estimated the overall gain in welfare to be around 1 percent of consumption, or perhaps slightly less. … It is about twice the welfare gain that I have elsewhere estimated would result from eliminating 10 percent points of inflation, and something like 20 times the gain from eliminating post-war sized business fluctuations. It is about 10 times the gain Arnold Harbenger once estimated from eliminating all product-market monopolies in the U.S."[4]

Based on our analysis, we estimate the cap-and-trade impact will probably be quite large as consumption constantly decreases, causing many negative economic results. In light of this evidence, it is important to assess the costs of global warming and determine whether they justify such large welfare losses.

What impact will constant, compounding consumption decreases have on individual American households? Table 4 presents the estimated impact of a 1% decrease in consumption for an average household of four people. Projections for business-as-usual scenario consumption are taken from Paltsev *et al*. (2008)

Table 4. Impact on Consumption of Average American Household

	2008*	2015	2030	2050
Population (Million)	301	321	359	397
Consumption (billion 2005$)	$8,217	$11,533	$17,761	$29,567
Consumption/Per capita (2005 $)	27,760	$35,928	$49,474	$74,476
Decrease in consumption per capita (2005 $)	$277	$359	$495	$745
Decrease for a family of 4 (2005 $)	$1,110	$1,437	$1,979	$2,979

*2005 data are used, 2008 are likely to be even higher.

We find that a mitigation path consistent with Lieberman-Warner's provisions is equivalent to a permanent tax increase for the average American household. This increase is projected to amount to an additional $1100 in taxes in 2008. Moreover, this cap-and-trade "tax" increases over time in real terms from about $1400 to $2000 during 2015-2030 and approximately $2000 to $3000 in 2030-2050. The de facto tax increase becomes quite significant when one considers the average American household spends about $2500 on food annually,[5] or approximately $208 monthly. The decrease in consumption per capita of $277 annually is equivalent to more than one month's food budget for the average American household, keeping other consumption levels constant.[6]

Another way to gauge this cap-and-trade tax impact is comparing it to auto-loan payments. For example, a new 2009 C-Class Mercedes can be leased for around $429 per month.[7] A decrease in consumption by $1110 amounts is equivalent to 2.5 monthly payments on this luxury car. This tax amounts to aboutlmost three and a half monthly payments in 2015 and almost seven payments in 2050.[8]

But the average American household usually does not buy a Mercedes. What about a Honda Civic? A new 2009 Honda Civic LX can be bought for around $189 a month.[9] A decrease in consumption by $1100 equals to almost six monthly payments on this car every twelve months in 2008 and fifteen monthly payments in 2050.

Clarifying our Message

Before we move on to discussing the cost estimates of other proposed legislation, we must clarify our message to avoid confusion. We find that the costs of mitigation are *equivalent* to a drop in consumption *levels*[10] below the business-as-usual scenario by 1%.

The Natural Resources Defense Council (NRDC) recently published a critical analysis of many of the analyses we have examined in this paper.[11] The NRDC suggests that abatement efforts, particularly cap-and-trade, will have only moderate impacts on welfare because the new system will not stop the economic growth of the U.S., but just make it slower.[12] For example, GDP growth in, say, 2015 might be 3% under cap-and-trade instead of 4% in its absence. Thus, the NRDC study criticizes some of the cap-and-trade studies we examined for suggesting that abatement would involve decreases in GDP rather than simply less overall growth.

We find that the costs of mitigation are *equivalent* to a drop in consumption *levels* below the business-as-usual scenario by 1%.[13] This does not mean that consumption or GDP would actually drop in 2008 by 1%. Most negative economic costs will be incurred in the future, when abatement targets become tighter. Our calculations demonstrate the future costs are *equivalent* to a permanent drop in consumption by 1% below today's level (continuing into the future) without the mitigation. That is, under abatement, the consumer's well-being will be the same as in the case when we cut consumption under no abatement by 1% in every year starting in 2008 and going into the future.

Of course, we could restate the same welfare costs in terms of a lower *growth rate* in consumption/GDP rather than drops in consumption *levels*. These are just alternative ways of measuring the welfare loss. We prefer balanced growth equivalent estimates since they are more standard in macroeconomic calibration exercises.

The fact that GDP does not drop below its 2008 level under the abatement scenario does not mean that the mitigation costs of mitigation will be small. The problem is that GDP drops below its *potential* level, the one that would have been attained if mitigation did not take place. Our analysis of available estimates suggests that the welfare costs of mitigation consistent with the provisions of Lieberman-Warner are going to be large as GDP consistently falls short of its potential.

Prices of Carbon Allowances

Lieberman-Warner's consequences for employment and the prices households pay for power and fuels hinge on the estimated price of carbon allowances, also called credits. An allowance's estimated price depends on the permissibility of banking of permits, offset availability, the technological development of carbon capture and sequestration (CCS) systems, and the number of different GHGs covered in addition to carbon dioxide).

Lieberman-Warner's impact on employment and energy and fuel prices hinge on the estimated price of carbon allowances. The estimated price of these allowances is highly sensitive to several assumptions. Among these assumptions are the availability and extent of banking of allowances, the availability of offsets, the development of CCS systems, and the number of different GHGs covered.

Lieberman-Warner provides for some banking of allowances, but the estimates from the CDA and ACCF/NAM do not include banking in their assumptions. Alternatively, the CRA study includes banking and estimates the presence of banking will cause the price of allowances to be higher prior to 2040, but considerably lower afterwards. The CRA study illustrates the presence of banking dramatically reduces the overall economic costs of cap-and-trade. The CRA estimates banking reduces the total estimated cost of Lieberman-Warner by $4.7 trillion dollars.

Many analyses test cost-estimate sensitivity by altering the number of foreign and domestic offsets available at a given time. Lieberman-Warner allows covered entities to use domestic and international offsets to cover up to 30% of total emissions. The analyses we examined typically restrict the number of offsets in the various cases that they examine. Lowering the number of potentially available offsets increases the price of permits, but it keeps total emissions closer to the mandated targets.

The studies also incorporate varying assumptions vis-à-vis the future feasibility of CCS and the construction of new low-carbon power plants. Many authors note that nuclear power is a low-carbon alternative to coal, but regulatory and societal objections present enormous problems for constructing new plants. Other "clean-energy" alternatives like wind and biomass are expected to have potential expansion issues as well. Some of the analyses also examine costs when CCS technology is either too expensive to be commercially viable or completely unavailable. Studies by ACCF/NAM and CDA assume alternative power is limited, the EIA and EPA studies test various assumptions about its CCS availability, and the MIT and CATF analyses contain no assumptions limiting nuclear, wind or CCS expansion.

Table 5: Carbon Allowance Price ($2007)

Group	Model	Scenario	Carbon Allowance Price 2015	Carbon Allowance Price 2030	Carbon Allowance Price 2050
MIT	EPPA	No Offsets, No CSS Subsidy	$59.15	$106.53	$233.42
		15% Offsets	$50.72	$91.35	$200.17
		CSS Subsidy	$57.91	$104.30	$228.52
		15% Offsets, CSS Subsidy	$50.44	$90.83	$199.03
ACCF/NAM*	NEMS	Low Cost	$36.69	$227.52	NA
		High Cost	$38.36	$271.27	NA
CRA	MRN-NEEM	Banking	$50.00	$90.00	$190.00
		No Banking	$40.00	$80.00	$350.00
CDA*	GI	Generous	$50.37	$69.90	NA
		Reasonable	$50.37	$90.46	NA
EPA	ADAGE	S. 2191	$30.55	$64.27	$167.53
	IGEM		$42.14	$87.45	$231.80
	ADAGE	S. 2191- No Offsets	NA	NA	NA
	IGEM		$81.13	$168.58	$447.79
	ADAGE	S. 2191- Constrained Nuclear, Biomass and CCS	$57.95	$118.01	$305.55
	IGEM		NA	NA	NA
EIA**	NEMS	S. 2191 Core	$30.84	$62.71	NA
		S. 2191 Limited Alternative/ No International Offsets	$78.12	$160.36	NA
CATF	NEMS	S. 2191	$17.43	$49.03	NA

* ACCF/NAM reports in the year 2014.
**EIA reports in the year 2020.
Prices converted to 2007$ using CPI

Finally, lower cost-estimates are achieved in scenarios where other GHGs in addition to carbon-dioxide count towards emissions. Lieberman-Warner covers a list of GHGs besides carbon dioxide; including methane besides merely carbon-dioxide, but only the CDA study limits reductions to carbon dioxide instead of the full array of GHGs. This partially explains why the CDA's cost-estimate predictions are relatively high. The CDA's estimates are even higher than the ACCF/NAM study's, which otherwise makes similar assumptions.

Impact on Employment

The assumptions driving the price of carbon allowances also affect employment. A higher predicted carbon allowance price gives producers a tighter margin and they are forced to shed jobs to maintain profit levels. The estimates of job losses range from hundreds of thousands to millions.

Three of the analyses model changes in employment. The ACCF/NAM, CDA and CRA estimate the net changes in employment. They assume that jobs will be created in new "green" industries, such as CCS power plants, replacing older and more carbon-intensive economic sectors. In each study, the changes in employment correlate with movements in the price of carbon allowances. The ACCF/NAM study shows carbon prices steadily rising as the number of allowances falls over time; as a result, the net change in employment is negative and increasing. The ACCF/NAM study predicts the loss of 850,000 to 1.86 million jobs in 2014 and up to 3.04 to 4.05 million jobs lost by 2030. Alternatively, the CDA study predicts an increase in employment of 120,000 jobs in 2015 as people are hired in the new "green" industries, under generous assumptions. However, the CDA predicts that more than 500,000 jobs could be lost by 2015 and approximately 430,000 to 460,000 by 2030.

The assumptions driving the price of carbon allowances also affect employment estimates. A higher predicted price of a carbon allowance gives producers a tighter margin and forces them to shed jobs in order to remain profitable. Both the ACCF/NAM and CDA assume that there is no banking of allowances, while the CRA includes banking. Banking allows entities covered by cap-and-trade to save allowances for future use. Without banking the price of allowances will start low, but rise quickly as the number of available permits falls. Naturally, banking drives up the price of allowances in 2015, but it allows the price to be lower than it would be without banking after 2040. In 2015, the CRA estimates that there will be 3.75 million jobs lost. The CRA study models job losses of up to 2.5 and 7.10 million in 2030 and 2050, respectively. The permissibility of allowance banking might explain why the CRA estimates of job losses are higher than the ACCF/NAM and CDA estimates in 2015.

Table 6: Change in Employment from Baseline

Group	Model	Scenario	Change in Employment from Baseline 2015 (millions of jobs)	Change in Employment from Baseline 2030 (millions of jobs)	Change in Employment from Baseline 2050 (millions of jobs)
ACCF/NAM*	NEMS	Low Cost	-.085	-3.04	NA
		High Cost	-1.86	4.0	NA
CRA	MRN-NEEM		-3.75	-2.5	-7.1
CDA*	GI	Generous	0.15	-0.46	NA
		Reasonable	-0.717	-0.43	NA

* ACCF/NAM reports in the year 2014.

Impact on Electricity Prices

Cap-and-trade will impact the prices households pay for electricity. Table 7 shows estimated changes in the electricity prices from the baseline year. Electricity prices are predicted to increase much more than gasoline prices. Lieberman-Warner's cap-and-trade system is estimated to increase the price of electricity by anywhere from 5% to 15% in 2015 and anywhere from 14% in the EPA core scenario to 128% in the ACCF/NAM's high cost scenario in 2030. The CATF model predicts a 7% increase from the 2005 price in 2030. The EIA, MIT, and ACCF/NAM studies predict a 10%, 37%, and 124% increase in electricity prices from their baseline scenarios to 2030, respectively. By 2050, electricity prices will have leveled off somewhat, returning to near 2015 levels according to the MIT and EPA estimates.

Table 7: Percent Change in Electricity Price from Baseline

Group	Model	Scenario	% Change from Baseline 2015	% Change from Baseline 2030	% Change from Baseline 2050
ACCF/NAM*	NEMS	Low Cost	14.00%	101.00%	NA
		High Cost	15.10%	128.40%	NA
CRA	MRN-NEEM		15.00%	35.00%	60.00%
EIA**	NEMS	S.2191 Core	5.20%	14.40%	NA
		S.2191 Limited Alternative/No International	26.90%	67.50%	NA

* ACCF/NAM reports in the year 2014.
**EIA reports in the year 2020.

Impact on Gasoline Prices

Cap-and-trade will burden households with higher gasoline prices. Table 8 shows the percent difference between the baseline gasoline price and the cap-and-trade adjusted price. All models and scenarios demonstrate that Lieberman-Warner will increase the price of gasoline above the reference scenario price but with large amounts of variation. The CRA predicts that gas prices rise 145% above the reference scenario in 2015. Yet, prices are only 30% higher than the reference scenario in 2030 because the higher CAFE standards are included in the 2030 baseline. The lowest estimates are CATF's and EPA's core scenarios, predicting increases of 11.6% and 16.7% by 2030, respectively. Alternative scenarios using higher-cost assumptions show increases from 41.2% to 145% by 2030.

Table 8a in the Appendix indicates the estimated change in the price of gasoline from the 2005 level. Most models predict that gasoline prices will steadily rise through 2050. In 2015, models that have more generous technology assumptions find that gas prices could be lower than they were in 2005; other models predict gas prices will be up to 25% higher than they were in 2005. By 2030, there is a wide spread in estimates. The CATF study has the lowest estimate of a 5% increase above the 2005 price. The MIT model and the strictest EIA models predict a 40% to 45% increase, while the ACCF/NAM model predicts 66% increase in the generous scenario and a 130% increase in the reasonable scenario. The MIT study, however, estimates that gas prices will hit their highest level in 2030 and return to 2015 levels (which are 20% higher than the 2005 price) by 2050. However, the EPA model predicts that 2050 gas prices will be 66% higher than the 2005 price.

We must note which models incorporate more stringent fuel efficiency mandates. Lieberman-Warner requires that all transportation fuels must become 10% less carbon intensive by 2020, similar in design to a Low-Carbon Fuel Standard. The CRA is the only analysis that incorporates this fuel requirement. This provision causes the price of gasoline to increase rapidly in the early part of the forecast; the addition of a severe fuel-efficiency assumption may be why the CRA's price estimates are higher than the others.

The other assumptions underpinning these models are rarely specified in the papers, but undoubtedly affect the gasoline price estimates. Many analyses are not clear in how they model changes in the prices of gasoline. Will gasoline producers simply pass along carbon permit costs to consumers? Only the CATF and EPA models explicitly state they assume the full cost of the carbon permit is ultimately borne by consumers.

Table 8: Percent Change in Gasoline Price from Baseline

Group	Model	Scenario	% Change from Baseline 2015	% Change from Baseline 2030	% Change from Baseline 2050
ACCF/NAM*	NEMS	Low Cost	13.00%	77.00%	NA
		High Cost	50.00%	145.00%	NA
CRA	MRN-NEEM		145.00%	30.00%	82.00%
EIA**	NEMS	S.2191 Core	9.30%	16.70%	NA
		S.2191 Limited Alternative/No International Offsets	20.30%	41.20%	NA
CATF	NEMS	S.2191	9.63%	0.12%	NA

* ACCF/NAM reports in the year 2014.
**EIA reports in the year 2020.

Impact on Natural Gas Prices

Table 9 shows the estimated increase in the price of natural gas from the baseline price. Under lower cost assumptions, the models predict that the price of natural gas will be from 12% to 17% higher in 2015 than the baseline cases. In cases with less generous assumptions, natural gas prices could experience increases of 20% to 49% higher than the baseline estimate in 2015. One thing is certain: any cap-and-trade system will increase the use of natural gas. Natural gas is the best alternative now available to non-CCS coal, so if we reduce coal-powered energy generation, we will probably rely heavily on natural gas as a substitute. By 2030, the increased reliance on natural gas will cause the estimated prices to rise 20% to 107% higher than baseline prices in low-cost scenarios and 87% to 145% in the high cost/limited alternatives cases.

Natural gas prices are particularly sensitive to the development of other low-carbon alternatives to existing coal-produced power. The pace and scope of CCS development has massive implications for future natural gas demand. For example, in an ACCF/NAM case assuming limited low-carbon alternatives to coal, natural gas prices rise more than 200% above 2005 levels by 2030. The EIA also predicts increases in the price of natural gas of around 200% in its limited alternative case by 2030. Even the EIA's core scenario predicts natural gas will cost 118% more in 2030. The MIT study also predicts that natural gas will be 64% higher than 2005. By 2050, MIT predicts natural gas prices will have declined slightly, but do not return to near the 2015 levels.

Table 9: Percent Change in Natural Gas Price from Baseline

Group	Model	Scenario	% Change from Baseline 2015	% Change from Baseline 2030	% Change from Baseline 2050
ACCF/NAM*	NEMS	Low Cost	17.90%	107.80%	NA
		High Cost	20.70%	145.70%	NA
CRA	MRN-NEEM		12.50%	20.00%	90.00%
EIA**	NEMS	S.2191 Core	14.20%	26.10%	NA
		S.2191 Limited Alternative/No International Offsets	49.50%	87.30%	NA

* ACCF/NAM reports in the year 2014.
**EIA reports in the year 2020.

Overall, our results demonstrate the implications of differing scenario assumptions and illustrate the massive economic challenges facing households if cap-and-trade becomes reality. For this reason, we emphasize that it is important to carefully assess the costs of global warming to see whether they justify the pain that mitigation efforts will cause the average American and his or her family.

III. Summaries of the estimates

Lieberman-Warner Climate Security Act

We start our review with the Lieberman-Warner Climate Security Act, legislation which received considerable attention before it was defeated on June 6, 2008 in the Senate.

Features of the Lieberman-Warner Climate Security Act (S. 2191)

- Limits total carbon-dioxide equivalent (CO_2e) emissions to 5775 million metric tons (mmt) in 2012 and to 1732 mmt in 2050. Reduces emissions of CO_2 and four other global warming pollutants by 4% in 2012, 19% in 2030, and 71% in 2050 below 2005 levels.[14] Mandates stricter targets for hydrofluocarbons (HFCs) emissions: 15% in 2020, 45% in 2030, and 70% in 2040 below 2005 levels.[15]
- Creates a tradable allowance system for the CO_2, CH4, perfluorinated compounds (PFCs), SF4, and HFCs. Converts four non-CO_2 GHGs such as methane into CO_2-equivalents (CO_2e) using Global Warming Potential (GWP) scale. Thus, it covers 86% of total GHG emissions.

- Requires upstream petroleum and natural gas producers, manufacturers of HFCs and PFCs (also known as F-gases) and nitrogen dioxide, and downstream facilities using more than 5,000 tons of coal per year to participate in the cap-and-trade system.
- Gives away a declining percentage of allowances (carbon credits) over time for free. Scarcity of allowances provides incentive for covered entities to develop and adopt carbon capture and storage (CCS) technologies. Remaining allowances are auctioned and the revenues used to fund low-carbon technology research and development.
- Awards domestic offsets based on a covered entity's performance in carbon capture and reducing non-covered GHG emissions. Domestic offsets may cover up 15% of total obligation. Permits the use of foreign allowances from comparable cap-and-trade systems (e.g., the Kyoto system) to cover an additional 15% of obligations.
- Establishes the Carbon Market Efficiency Board with authority to monitor banking of allowances and potentially adjust the number of allowances created on year-to-year basis.

Seven Analyses of Lieberman-Warner

In this section we review and compare seven cost estimates of the Lieberman-Warner's abatement schedule.

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1. Model: Emissions Prediction and Policy Analysis (EPPA)

Organization: Massachusetts Institute of Technology (MIT) Joint Program on the Science and Policy of Global Change

Authors: Sergey Paltsev, John M. Reily, Henry D. Jacoby, Angelo C. Gurgel, Gilbert E. Metcalf, Andrei P. Sokolov and Jennifer F. Holak

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Paltsev *et al*. use MIT's Emissions Prediction and Policy Analysis (EPPA) model to estimate the legislation's effects on total emissions in the United States, the price of energy and the resulting effects on consumer welfare. The MIT study included some particular provisions found in Lieberman-Warner: upstream implementation, inclusions of non-CO_2 gases, the crediting of allowances for reducing non-covered emissions, banking of allowances, and the distribution of allowances as incentive to use carbon capture and storage (CCS) technology.

The analysis tests various stringency assumptions by changing the amount of offsets available and the effect of a government subsidy for CCS. It specifically does not estimate how Lieberman-Warner interacts with other federal emissions mandates (for instance, H.R. 6), nor the effects of both free distribution and auctioning of allowances.

The MIT study presents a baseline scenario and four other scenarios. The strictest scenario does not allow any offsets nor does it include the federal subsidy for CCS technology research and development. The second scenario relaxes the offset restriction to cover up to 15% of emissions and assumes that foreign offsets are too costly. The third scenario returns offset availability to zero and adds the CCS subsidy. The fourth and final scenario's assumptions are the most like Lieberman-Warner's provisions. This scenario allows both 15% offsets and the CCS subsidy.

Under the assumptions mentioned above, the paper finds that price of an allowance will rise steadily over time as total emissions levels fall from 5775 mmt in 2012 to 1732 mmt in 2050. Allowance costs range from $47 to $56 under their strictest assumptions in 2015 and rise to $188 to $221 by 2030.[16] The EPPA model predicts GDP in 2015 will be 0.65% lower than baseline GDP in the strictest scenario and 0.57% lower in the more relaxed case. By 2050, GDP is estimated to be 1.1% to 0.75% lower in the strictest and least strict cases.

The economy-wide amount of consumption spending falls due to allowance price increases that firms pass on to consumers. The model predicts that consumption could fall from 0.29% to 0.37% in 2015 and 2.01% to 2.36% in 2050. The authors use equivalent variation techniques to measure the effects on consumer welfare; essentially, equivalent variation gauges how much a person would pay to avoid an increase in prices. The model predicts that welfare loss would be 0.7% in 2015 in both the cases and would be 1.81% and 1.54% in 2050. Stated another way, consumers would be willing to pay $9.7 billion to avoid the price increases that S. 2191 creates in 2015 and they would be willing to pay $554.2 billion to avoid the price increase in 2050 (in the least strict model).

The paper also estimates that by 2050, the prices of petroleum products will increase by around 22%, natural gas by around 82% and electricity by around 61% from 2005 levels.

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2. Model: National Energy Modeling System (NEMS)

Organizations: American Council for Capital Formation (ACCF) and National Association of Manufacturers (NAM)

Authors: Science Applications International Corporation (SAIC)

The analysis in this paper was conducted by SAIC based on the parameters determined by the ACCF and NAM. The paper uses the National Energy Modeling System (NEMS) to estimate Lieberman-Warner's effects on national economic indicators and energy production and prices. The estimate includes H.R. 6[17] mandates as well as updated construction costs for power generating facilities.

The ACCF and NAM study models two different scenarios, which they label "low cost" and "high cost." Under the low-cost scenario, offsets are available to cover more than 20% of emissions; future energy prices are determined by long-term predictions contained in the *Annual Energy Outlook (AEO) 2008* report, and every type of power generation faces long-term constraints. The high-cost scenario circumscribes the available offsets to between 15% and 20%, uses the *AEO 2007* High Profile Side case (a worst-case scenario prediction) to determine future energy prices, and places tighter caps on building new power plant infrastructure. Neither scenario permits the banking of allowances.

Under these assumptions, SAIC finds that carbon allowance prices will rise from $36.69 in 2014 to $271.27 in 2030.[18, 19] GDP decreases as the allowance price rises over the forecasted period. In 2014, GDP is 0.8% lower than the baseline in the low cost scenario and 1.6% lower in the high cost scenario. By 2030, GDP is 2.6% and 2.7% lower than the baseline in the low cost and high cost scenarios, respectively. Higher production costs cause net job losses to range from 0.85 million jobs to 1.86 million jobs in 2014 and 3.04 million jobs to 4.05 million jobs in 2030.

The model estimates that the loss to the average household income would be 1.0% to 2.8% in 2014 to 2.9% to 4.9% in 2030. The paper also estimates that the residential price of electricity will rise by about 13% above the baseline in 2014 and between 101% and 129% in 2030. Natural gas is also predicted to rise from 18% to 21% in 2014 and by 108% to 146% in 2030. Total expenditures on energy due to the price increases rise from 15.5% to 33.5% in 2014 to 78.7% to 114.5% in 2030.

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3. Model: Multi-Region National (MRN-NEEM)

Organization: CRA International

Authors: W. David Montgomery, Anne E. Smith

CRA International uses MRN-NEEM, which is a "multi-region national" model integrating a macroeconomic model of all economic sectors including consumer income, consumption, investment, and trade with a model of the energy and non-energy sectors. It predicts Lieberman-Warner's effects on total GHG emissions, price of the carbon allowances and energy, as well as the share of total power of various types of power generation.

The CRA model includes most of Lieberman-Warner's provisions, specifically its low carbon fuel standards and the CCS subsidy, as well integrating the HR 6 provisions. It builds a baseline scenario using the *Annual Energy Outlook 2008* to predict future energy costs and the increased CAFE standards, renewable fuel standards and appliance efficiency standards mandated by H.R. 6.

This paper finds carbon allowance prices start at around $50, rise to around $80 by 2030, and culminate at $190 by 2050.[20] The CRA study also provides cost estimates in the absence of allowance banking. The allowance price without banking remains lower than under scenarios including banking until 2040. After 2040, allowance prices rise sharply due to the high abatement costs that firms would incur within the next twenty years; therefore, firms prefer to be net borrowers of allowances in the short run. The CRA study estimates that allowing the banking of allowances reduces the present discounted costs of Lieberman-Warner by $100 billion.

The model predicts Lieberman-Warner would cause GDP to fall by 1.9% in 2015. The legislation's effects are blunted from 2025 to 2035 because of the CAFE standards already in place in the baseline. However, by 2050 GDP falls by nearly 3.5% because emissions caps become increasingly strict. CRA estimates the present discounted cost at approximately $5.3 trillion by 2050.

The cost per household is estimated to be over $2,000 (or 4.5% of household income) in 2015, falling to just above $1,000 (2% of household income) in 2025 and rising again to $2,000 by 2050 (assuming an average household income of $50,000). CRA also estimates the loss in employment to be nearly 4 million jobs in 2015 and over 7 million by 2050.

The prices of motor fuel, natural gas and electricity noticeably rise. In 2015, electricity and natural gas prices are around 15% above the baseline estimate and motor fuel might climb over 140% higher. By 2050, motor fuel and natural gas are around 90% higher than the baseline and electricity prices might increase by as much as 60%.

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4. Model: Applied Dynamic Analysis of the Global Economy (ADAGE) and Intertemporal General Equilibrium Model (IGEM)

Organization: Environmental Protection Agency (EPA)

In this study, the EPA estimated Lieberman-Warner's implications for GHG emissions, the price of energy and the resulting impacts on other economic indicators. The EPA uses two models, ADAGE and IGEM,[21] to provide three baseline scenarios and seven alternative scenarios accounting for various technology developments, energy costs and allowance availabilities. Specifically, the EPA tests the sensitivity of estimates by constraining the growth of technology like nuclear, biomass and carbon capture and storage (CCS), by assuming no new international agreements going beyond the requirements of the Kyoto Protocol, and circumscribing offset availability. All cases permit allowance banking and base future energy prices on the *Annual Energy Outlook 2006* predictions. However, no scenarios include other GHG reduction measures such as H.R. 6 and its vast efficiency mandates.

The price of a carbon allowance under its core scenario assumptions is $29 in 2015 and increases to $159 in 2050, as estimated by ADAGE, and $40 in 2015, increasing to $220 in 2050, as estimated by IGEM.[22] The scenario in which no offsets are available estimates the highest prices of $77 in 2015 and $425 in 2050. The "high technology" Lieberman-Warner case estimates the lowest prices at $22 in 2015 rising to $121 in 2050.

The increased cost of energy lowers GDP by 0.18% in 2010, 0.9% in 2030 and 2.37% in 2050 according to ADAGE predictions of the baseline versus the core scenario. IGEM predicts more dire consequences to GDP, showing a loss of 0.94% in 2010, 3.76% in 2030 and 6.9% in 2050.[23] ADAGE predicts losses to total U.S. consumption of 0.43% in 2020 and 2.10% in 2050. IGEM predicts even larger losses of 0.66% in 2020 and 3.26% in 2050

According to ADAGE, households are estimated to lose about $446 in consumption or 0.43% of the baseline estimate in 2015. This number increases to $3,984 in 2050 or 3.26% less than the baseline household consumption. The price of a gallon of gasoline in 2030 is estimated to be $3.11. These estimates of future oil prices do no take into account interruptions in supply or temporary changes in the price and only represent the expected cost changes due to the law. Electricity prices will rise over the forecast period from the 2005 price by nearly 20% in 2015, 30% in 2030 and then fall back to 20% over the 2005 level in 2050.

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5. Model: National Energy Modeling System (NEMS)

Group: Energy Information Administration (EIA)

The EIA is an agency within the Department of Energy and uses the National Energy Modeling System (NEMS) for its forecasts. The model provides a baseline which includes H.R. 6, the Energy Independence and Security Act of 2007 (EISA), estimates of voluntary low-carbon technology adaptation (provided by the EPA), and forecasts of energy prices provided by the *Annual Energy Outlook (AEO) 2008*.

The "core" scenario models the cap-and-trade system for Group I GHGs (as defined in the legislation's text), the bonus credit for carbon capture and storage (CCS), and some other features present in Lieberman-Warner. The EIA study presents five other scenarios in which differing assumptions—no international offsets available, high costs for electricity generating facilities, limited alternatives to coal power, and both limited alternatives to coal and no international offsets—are made.

The EIA study predicts that the price of a carbon allowance will be $30 in 2020 and $61 in 2030 under the core scenario assumptions. The highest estimated price is found in the strictest case—limited alternatives and no international offsets—and is $76 in 2020 and $85 in 2030.[24]

6. Model: Global Insight

Organization: The Heritage Foundation's Center for Data Analysis (CDA)

Authors: William W. Beach, David W. Kreutzer, Ben Lieberman, and Nicolas D. Loris

The CDA uses a model developed by Global Insight. This study baseline scenario incorporates important elements of previously enacted energy legislation[25] in addition to some critical provisions of Lieberman-Warner. However, the study only caps carbon-dioxide emissions, rather than all GHGs covered by the legislation. Furthermore, in further contrast to Lieberman-Warner, it does not countenance allowance banking in any of its scenarios.[26]

The CDA models two different scenarios — "generous" and "reasonable" — both constraining nuclear power production to its current level, reflecting the difficulty in expanding production. In the "generous" case, key technologies such as carbon capture and storage (CCS) are ready to be deployed when it becomes cost effective to use them. Alternatively, in the "reasonable" scenario, those key technologies do not exist within a twenty-year forecast.

The price of a carbon allowance is $49 in both the generous and reasonable forecasts in 2015. By 2030, the price rises to $68 in the generous model and $88 in the reasonable model. The generous forecast predicts that GDP will be 0.55% lower than the baseline in 2016 and 2030, while the reasonable forecast predicts GDP will be 1.41% lower in 2016 and 2.17% lower in 2030. The economy loses 166,000 jobs on net in 2016 and 461,000 jobs in 2030 according to the generous assumptions. The reasonable forecast predicts 855,000 fewer jobs than the baseline in 2016 and 431,000 fewer jobs in 2030. In 2016, personal consumption is predicted to fall by 0.89% under the generous assumptions and 1.61% in the reasonable forecast. By 2030, the predicted loss to personal consumption has been mitigated somewhat and is estimated to be 0.48% under the generous assumptions and 0.93% under the reasonable assumptions.

7. Model: NEMS

Group: Clean Air Task Force (CATF)

Author: Jonathan Banks

The CATF uses the National Energy Modeling System (NEMS) and assumes that technology improves according to the Energy Information Administration's "best available technology" schedule, but that biomass energy production is severely circumscribed. CATF includes unlimited banking of allowances and uses the revenue from the auction of allowances to fund a CCS tax credit. The CATF did not incorporate the new low carbon fuel efficiency standards or limits on the future sources of power like nuclear or wind.

The study finds that the price of a carbon allowance starts at just over $15 in 2015 and rises to $45 in 2030 as the number of carbon allowances created falls. GDP falls by 0.7% in 2030, placing predicted economic growth four months behind the business-as-usual case. Per capita GDP falls by 0.9% from the reference case by 2030.[27]

The CATF study also claims that real spending on electricity falls from 2007 to 2030 due to improvements in end-use efficiency, though the price of electricity rises. Similarly, the price of natural gas rises, but real yearly expenditures on natural gas increase by only a dollar from 2007 to 2030. CATF also estimates that the cost of carbon allowances is almost completely passed through to the consumer, raising the price of gasoline by roughly $0.10 for every $10 per ton of CO_2.

While other studies show that natural gas power generation increases until the point at which CCS becomes economic, this study shows that the subsidies for CCS cause it to enter earlier, and thus the price of natural gas does not have to rise as much as would be expected to otherwise. However, the study does note that if either CCS or nuclear power is not allowed to expand for political or technological reasons, then natural gas will fill in the gap that coal-burning plants leave. The study does not predict that coal without CCS will be removed from the market by 2030 and will still represent around 150 gigawatts of power supply.

IV. Other Proposals

Bingaman-Specter Low Carbon Economy Act of 2007

The Bingaman-Specter Low Carbon Economy Act, introduced in June 2007, would create a cap-and-trade system for greenhouse gases similar to Lieberman-Warner. Bingaman-Specter caps total covered emissions (CO_2e) at 660 mmt in 2015. The government would lower the amount of allowances created until 2050, when the allowance cap would reduce emissions to 60% of 1990 levels (1927 mmt of CO_2-e). As the number of allowances auctioned is lowered, the price of an allowances will rise. Many industries fear that abatement will be very costly and so the only option will be to emit and purchase allowances, which will cause the price of an allowance to be very high. To allay those fears, Bingaman-Specter institutes a “safety valve” called a Technology Accelerator Payment (TAP), which essentially is an upper limit on a price of carbon allowances.[28] If the price of an allowance ever rises above the TAP price, then the cap-and-trade system becomes essentially a tax on carbon emissions. Regulated entities can always meet their obligation by paying the TAP price, which is set at $12 in 2012 and grows at 5% per year in real terms. Because of this, the price of an auctioned allowance will never exceed the TAP price. A percentage of allowances, declining over time, is given away free to regulated entities; there are also allowance bonuses allotted for reducing GHGs from non-covered emissions and federal subsidies for CCS technology.

The EIA used the National Energy Modeling System (NEMS) to estimate the economic impact of Bingaman-Specter. The EIA estimates two reference cases. In both cases the EIA uses the energy price forecasts from the *AEO 2007*. However, in one case they estimate the effects of the law using more optimistic assumptions on the availability of technology. The major features of S. 1766 that the EIA tests are the cap-and-trade limits, the TAP price, and bonus credits for CCS and non-energy abatement. For sensitivity, the EIA tests a scenario in which the CCS bonus is only half of what S. 1766 uses, a scenario with optimistic technology assumptions, a scenario with supporting environmental policies like H.R. 6, a scenario with both optimistic technology assumptions supporting policies, and a scenario with limited alternatives to coal.

In each scenario, the TAP program is activated by 2030 and the price of an allowance does not rise above the TAP price for that year. Only in the "high technology" case in 2020 does the EIA predict that the price of an allowance is lower than the TAP price. Because of the TAP, total emissions in 2020 and 2030 are expected to exceed the total covered emissions. In all of the cases except limited alternatives to coal, in 2015 GDP is higher with S. 1766 than the predicted baseline. By 2030, most scenarios are nearly equivalent to the baseline, but the core S. 1766 GDP is around 0.05% below the baseline and the limited alternative scenario predicts GDP will be 0.25% below baseline. As higher energy costs raise prices across the economy, real consumption falls by about 0.1% from the baseline in 2030 in the core scenario and by 0.2% in the limited alternatives scenario.

The cost of the allowances is passed forward into higher prices for gasoline, natural gas and electricity. In 2020, gasoline prices are predicted to be 0.06% higher than baseline, natural gas prices are predicted to be 0.7% higher, and electricity prices are predicted to be 0.5% higher. By 2030, gasoline and natural gas are predicted to be 0.8% higher and electricity is predicted to be 0.085% higher. The limited alternatives scenario predicts a small (less than .01 percentage points) increase in the prices of these goods.

Carbon Tax Proposals

Metcalf *et al*. (2008) employ MIT's Emission Prediction and Policy Analysis (EPPA) to estimate the effects of the carbon taxes on CO_2 emissions, welfare costs, prices of consumer goods, tax revenues, and the effects on each income decile. Each tax proposal varies in the level of the tax and the way in which the tax grows — or remains constant — over time. The estimated costs to consumer welfare vary with each plan, from a nearly 1% gain under the least stringent plan to a 2% loss under the most stringent. Using information from the Consumer Expenditure Survey, the authors show that the carbon tax is regressive, but a lump sum per capita return of tax revenues is progressive. Each proposal considered taxes only on carbon, buthowever, if the taxes are extended to cover all greenhouse gases (GHGs), there are significant reductions in the lost consumer welfare. The authors also make comparisons between the tax plans and comparable cap-and-trade proposals and find there is little difference.

The three different plans analyzed are named for their main proponents in Congress, Dingell,[29] Larson,[30] and Stark-McDermott.[31] The Dingell bill proposes a $13.64 tax per ton of CO_2 emitted along with a separate tax on gasoline of $0.50 per gallon; neither tax changes over time.[32] The Larson bill has an initial tax rate of $19.96 that grows in real terms of 10% per year. The Stark bill has an initial rate of $10 that grows in nominal terms of $10 annually. Each bill has its own plan for using the tax revenues.

Metcalf *et al.* (2008) predict the level of GHG emissions over time for each plan.[33] The Dingell bill is the least stringent plan and as such has the smallest effect on total emissions. This plan keeps total emissions at current levels until 2025, when emissions begin increasing at a rate comparable to the "business-as-usual" reference scenario. In 2050, the plan reduces emissions to 12 billion metric tons (bmt) per year from 13.5 bmt in the reference scenario. The Stark bill manages to keep total emissions constant at today's levels of 8 bmt per year. The Larson bill's relatively high tax rate reduces emissions to 4 bmt per year or roughly half of the current emission levels and 40% of the reference emission levels.

The EPPA model predicts the welfare costs of each plan. These costs include changes in market consumption as well as effects on leisure. The aggregate present discounted welfare change for the Dingell plan is a 0.01% gain in welfare due to the EPPA model's assumption that other countries will take steps to reduce emissions that in effect lower oil prices. The Stark plan has a slight loss to welfare of 0.03%. The Larson plan has the largest effect of a 1.2% reduction in present discounted aggregate welfare.

The authors also model the tax plans covering non-CO_2 GHGs. Since initial abatement for any gas is easier than subsequent reductions, extending the tax plan to cover all GHGs can result in significant decrease in the tax rate. In fact, when more GHGs are included, the tax rate required to get to the same reduction in total emissions as under a carbon-only tax falls under each plan. The Larson plan's initial tax rate could be reduced to $13.30 per metric ton of CO_2 emitted, the Stark plan's initial tax rate could be reduced to $1.50 and the Dingell plan's initial rate could be reduced to $12.80. Lowering the tax rate also reduces the welfare costs of each plan. The net present value of the aggregate welfare costs is reduced from 0.3% to 0.11%.

The tax revenue from each tax plan is substantial and can be returned to consumers in such a way as to mitigate and even reverse the regressive nature of the carbon tax. In 2015, the potential tax revenues from the plans are $88, $69 and $126 billion per year from the Dingell, Stark and Larson plans, respectively. These tax revenues could account for 4% of total Federal tax revenue under the Stark plan and up to 7% under the Larson plan. As the tax rate in the Stark and Larson plans rises over time, revenues increase substantially; for the Larson plan in 2050 the carbon tax revenues would account for 21% of Federal tax revenue.

Using EPPA predictions on increases in prices on electricity, gasoline and other consumer goods of a generic $15 tax per ton of CO_2 emitted and information from the Consumer Expenditure Survey, the carbon tax is found to be regressive, but the level of its regressivity depends on a number of key assumptions. The first assumption is that consumers do not change behavior. If the full amount of the tax is shifted onto the consumer, then the poorest 10% of the population faces a 3.7% reduction in income while the richest 10% faces a 0.8% reduction in income. However, a per capita lump sum return of the tax revenue would actually result in making the carbon tax plan progressive. Another positive effect of a carbon tax is that the revenue can be used to reduce taxes on labor or capital and, thus, increase overall economic efficiency.

Conclusion

In this paper we have provided a brief summary of estimates of the greenhouse gases emissions' abatement costs with particular focus on households.

GDP reduction estimates vary widely from 0.3% to 3% drop below business-as-usual in 2015 and from 1% to 10% in 2050. The timeframes of new technology development and growth potential of existing clean sources of energy, availability of offsets (domestic and international), and permissibility of allowance banking are likely to account for most of these differences.

Consumption costs are affected by the same factors as GDP costs. Therefore, studies which assume limited alternative sources of energy and/or limited offsets usually predict smaller decreases in consumption than those which do not make such assumptions. (Estimated costs could differ by a factor of 2-3).

Despite the differences in estimates, our analysis strongly indicates the abatement costs could cause around a 0.8%-1% of drop in consumption below the business-as-usual scenario. This is a conservative estimate; many studies project that costs are likely to be even higher. Given these estimates, we can conclude that the costs of mitigation are likely to be huge.

Our research indicates that quantifying the costs of proposed policies dealing with climate change is a vital prerequisite to determining the appropriate course of action.

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Appendix

Summary of Assumptions of the Models

MIT: EPPA

- Banking of allowances
- No use of foreign allowances
- Four Cases
  - o No Domestic Offsets; No CCS Subsidy
  - o CCS Subsidy
  - o 15% Domestic Offsets
  - o 15% Domestic Offsets; CCS Subsidy

ACCF/NAM: NEMS

- No banking of allowances
- Caps on nuclear, sequestered coal-fired (IGCC) generation, sequestered natural gas-fired (NGCC), biomass and wind energy
- Estimated capital costs of new plant construction
- Two Cases
  - o Low Cost
    - Greater than 20% Offsets
    - *AEO 2008* Oil Prices
  - o High Cost
    - 15% to 20% Offsets
    - *AEO 2007* "High Profile Side Case" Oil Prices
    - Tighter caps on nuclear, sequestered coal-fired (IGCC) generation, sequestered natural gas-fired (NGCC), biomass and wind energy

CRA: MRN-NEEM

- Banking of allowances and one scenario of no banking
- *AEO 2008* natural gas prices, electricity demand growth, non-electric CO_2 emissions
- Includes effects of H.R. 6
  - o CAFE standards
  - o Renewable Fuel Standard (RFS)
  - o Efficiency standards on power supplies and some appliances

EPA: ADAGE and IGEM

- Banking of allowances
- *AEO 2006*
- Three baseline estimations
    - o Normal
    - o High technology
    - o High technology and international actions
- Seven Cases
    - o Encapsulate different assumptions on prices, offset availability, technology growth, limitations on nuclear power and actions of other nations

CDA: Global Insight

- No banking of allowances
- Focus on CO2 only
- Two Cases
    - o Reasonable
        - ☐ Assumes CCS does not develop with 20- year forecast
        - ☐ No nuclear power beyond the base case
    - o Generous
        - ☐ Assumes CCS is used for any coal-fired power plant built after 2018
        - ☐ No nuclear power beyond the base case

EIA: NEMS

- Banking of allowances
- 6 Cases
    - o Baseline
    - o S. 2191 Core
    - o High Cost
    - o Limited Alternative to Coal
    - o No International Offsets
    - o Limited Alternatives and No International Offsets
    - o S. 1766

CATF: NEMS

- S. 2191
    - o Banking of allowances
    - o 30% Offsets
    - o Bonuses and Subsidies for CCS
    - o Subsidies for geological carbon sequestration (GCS), energy efficiency
    - o Money to offset electric and natural gas price increases
    - o Constrains deployment of biomass
    - o Unlimited nuclear growth
    - o EIA's "Best Available Technology" Case

Estimating the Impact on Consumption Assumptions and Technical Details

In this section we describe how to compute the balanced growth equivalent to the mitigation path consistent with the Lieberman-Warner bill's. To find the balanced growth equivalent, we calculate the fraction that consumption must decrease below the business-as-usual model in order to provide an individual the same level of utility/well-being as the abatement scenario.

Assumptions

In order to find that fraction we make the following five assumptions:

First, we assume a representative consumer with a constant elasticity of substitution (CES) utility function with a risk aversion parameter of 1 or 2. Consumers typically prefer minor changes in consumption over a longer period of time to a large one-time change. The risk aversion parameter captures how much a consumer dislikes a volatile consumption stream. Values of this parameter around 1 and 2 are fairly standard in macroeconomic calibration exercises, and these figures are consistent with the assumptions made in Stern (2007) and Lucas (1990). Estimated costs differ only in the fourth digit when we change risk aversion parameter. Thus, we present only one of the estimates in Table 2.

The second important assumption is that the rate of pure time preferences is about 3%-4%. The time preference reflects the consumer's desire, other things being equal, to consume today rather than tomorrow. This is consistent with Lucas (1989, 1990). If we follow Stern (2007) and assume this figure to be 0.1%, we are likely to get much higher estimates, though many authors argue that such choice of rate of time preference would be too low.[34]

Third, we need to account for growth in the U.S. population when computing social welfare. We assume that population grows at 0.6% annually, following Paltsev *et al.* (2008).

Fourth, we must make assumptions concerning how consumption fluctuates in the intervening years between 2015, 2030 and 2050, since we only have cost estimates for those specific years. We use linear interpolation between the intervals so that decrease in consumption changes linearly between 2015 and 2030, and 2030 and 2050 to attain the estimated values presented in Table 3.

Finally, where the risk aversion parameter is 2, we assume that consumption per capita grows at 2% annually under a business-as-usual scenario, following the Paltsev *et al.* (2008) model. As we show in the technical appendix, when the risk aversion coefficient is 1, we do not need to make any assumptions about consumption growth.[35] Since the estimates for the two risk-aversion numbers are virtually the same, this last assumption does not make a big impact on the results.

Technical Details

Consider an artificial economy with a single infinitely-lived consumer who has the same consumption stream as the aggregate consumption. We assume that the consumer maximizes discounted sum of utilities of the form:

$$U = \sum_{t=0}^{T} \exp(-\rho t) u(C_t) N_t$$

Here $N_t = N_0 \exp(nt)$ is the population in period *t*, where *n* is the rate of population growth. Following current population growth projections (e.g., Paltsev *et al.*, 2008), we can assume that population grows at about 0.6% to 0.8% (Assumption 3).

$u(c_t) = \frac{c^{1-\sigma}}{1-\sigma}$ is an instantaneous utility function, describing the utility derived from consumption at a given point in time. The assumption of this particular utility form is standard in macroeconomics and usually σ is assumed to be somewhere between and 4, see e.g., Lucas (1990) (Assumption 1).

$\rho > 0$ is the rate of pure time preference. We assume it to be 3-4% (Assumption 2).

Also let under the business-as-usual scenario, i.e., without the costs of mitigation and the costs of climate change, consumption grows at the constant rate *g*. Thus, consumption would evolve as:

$C_t = C_0 \exp(gt)$.

Following Paltsev *et al.* (2008), we assume that g=2% under a business-as-usual scenario.[36] Given the recent economic situation, this number probably should be adjusted downward. (Assumption 5)

The Lieberman-Warner Act requires some abatement of GHG emissions which would result in decreased consumption by some fraction α_t. Table 3 provides estimates for α_t in 2015, 2030, and 2050. We use linear interpolation (Assumption 4) to approximate consumption drops in other years). Thus the consumption path under Lieberman-Warner or a similar policy becomes:

$$C_t^{LW} = C_0 \exp(gt)(1-\alpha_t)$$

Our task is to compute constant growth equivalent to this path, i.e., to compute λ such that if consumption declines by fraction λ below the business-as-usual path, then the consumer would get the same utility as under the LW path above: i.e., would bring the same utility as under the LW path above:

i.e., $C_t^{*LW} = C_0 \exp(gt)(1-\lambda)$ would bring the same utility as $C_t^{LW} = C_0 \exp(gt)(1-\alpha_t)$.

This means that:

$$U(LW) = U(LW^*) \Leftrightarrow \sum_{t=0}^{T} \exp(-\rho t) u(C_t^{LW}) N_t = \sum_{t=0}^{T} \exp(-\rho t) u(C_t^{LW^*}) N_t$$

Substitution definitions of C_t^{LW} and C_t^{LW*} one gets that λ should solve:

$$\sum_{t=0}^{T} \exp(-\rho t) \frac{(C_0 \exp(gt)(1-\alpha_t))^{1-\sigma}}{1-\sigma} N_0 \exp(nt) = \sum_{t=0}^{T} \exp(-\rho t) \frac{(C_0 \exp(gt)(1-\gamma))^{1-\sigma}}{1-\sigma} N_0 \exp(nt)$$

or equivalently:

$$\sum_{t=0}^{T} q^t (1-\alpha_t)^{1-\sigma} = \sum_{t=0}^{T} q^t (1-\lambda)^{1-\sigma}$$

where $q = \exp(n + (1-\sigma)g - \rho)$. Thus, we can find the necessary drop in consumption λ from the following equation:

$$(1-\lambda)^{1-\sigma} = \frac{\sum_{t=0}^{T} q^t (1-\alpha_t)^{1-\sigma}}{\sum_{t=0}^{T} q^t}$$

This is the equation we use to compute the estimates of consumption drops. Since α_t are given only at 2015, 2030 and 2050, we use linear interpolation to infer the value of consumption drops in other years, i.e., we assume that in other years α_t changes linearly between known values in years 2015, 2030, and 2050.

There is slight disadvantage to the approach above. We need to make an assumption about the growth rate of consumption in the business-as-usual scenario. It appears that in a particular case we can overcome this problem.

Assume that the instantaneous utility function is logarithmic. This approach has the advantage that now we need not make specific assumptions about the path of consumption under the business-as-usual scenario. As the derivation below shows, under the log specification, estimated growth equivalent costs of mitigation will not depend on the path of consumption under the business-as-usual scenario. Yet the disadvantage is that some economists would argue that $\sigma = 1$ may be a bit too low.[37]

In this case, constant (in percentage terms) drop in consumption λ would solve:

$$\sum_{t=0}^{T} \exp(-\rho t) \log[C_t(1-\alpha_t)] N_0 \exp(nt) = \sum_{t=0}^{T} \exp(-\rho t) \log[C_t(1-\lambda)] N_0 \exp(nt)$$

Note that $\log C_t$ cancels from both sides of the equation above, hence λ will satisfy.

$$\sum_{t=0}^{T} \exp((n-\rho)t) \log(1-\alpha_t) = \sum_{t=0}^{T} \exp((n-\rho)t) \log(1-\lambda)$$

Thus λ solves:

$$\log(1-\lambda) = \frac{\sum_{t=0}^{T} \exp((n-\rho)t) \log(1-\alpha_t)}{\sum_{t=0}^{T} \exp((n-\rho)t)}$$

Using the outlined method for each of the scenarios in Table 2, we computed constant-over-time loss in consumption equivalent to estimated losses in consumption reported by Table 3. This constant loss is to be incurred every year starting today (2008) and going into the future up to 2050 or 2030. We stop our calculations at those time horizons because the studies do not model impacts of abatement on consumption beyond that timeframe.

However, most studies show that over time, consumption would drop more and more below its no-abatement level. In this regard, our estimate provides a lower bound. Also under a rate of time preference around 3-4%, anything happening after 2050 is unlikely to have any sizeable impact on our figures. For the studies which stopped at 2030, we compute two estimates: one for the horizon up to 2030, the other for the horizon up to 2050 with the assumption that damages between 2050 and 2030 are the same as the last available estimate, the one in 2030. We see that in this case, the estimate of the costs of mitigation will be even higher.

Text of the Program

```
% This program is used to compute the impact on consumption of the
% mitigation path consistent with Lieberman Warner Climate Security Act of
% 2007 S2191
n=0.006 % population growth
g=0.02 % consumption under BAU scenario
rho=0.04 % rate of pure time preference
gamma=2 % elasticity of substitution
q=exp(n+(1-gamma)*g-rho)
t0=2008;
T=2050;
for j=1:length(data(:,1))
alpha15=data(j,1);
alpha30=data(j,2);
alpha50=data(j,3);
for t=t0:T
   if t<=2015
      alpha(t-t0+1)=0+alpha15*(t-t0)/(2015-t0);
   else
      if t<=2030
         alpha(t-t0+1)=alpha15+(alpha30-alpha15)*(t-2015)/(2030-2015);
      else
         alpha(t-t0+1)=alpha30+(alpha50-alpha30)*(t-2030)/(2050-2030);
      end
   end
end
SA=0;
S=0;
for t=t0:T
   SA=SA+(q^(t-t0))*((1-alpha(t-t0+1))^(1-gamma));
   S=S+(q^(t-t0));
end
Percent(j)=100-(SA/S)^(1/(1-gamma))*100
%log drop
ql=exp(n-rho);
SAl=0;
Sl=0;
for t=t0:T
   SAl=SAl+(q^(t-t0))*log(1-alpha(t-t0+1));
   Sl=Sl+(q^(t-t0));
end
Percentl(j)=100-exp(SAl/Sl)*100
End
```

Tables

Table 7a: Change in Index of Electricity Gas Price (Index, 2005=1)

Group	Model	Scenario	Index 2015	Index 2030	Index 2050
MIT	EPPA	No Offsets, No CSS Subsidy	1.61	1.81	1.61
		15% Offsets	1.56	1.79	1.6
		CSS Subsidy	1.6	1.57	1.61
		15% Offsets, CSS Subsidy	1.55	1.57	1.61
ACCF/NAM*	NEMS	Low Cost	1.16	2.24	NA
		High Cost	1.17	2.54	NA
EPA**	ADAGE	S. 2191	1.1	1.3	1.2
	IGEM		NA	NA	NA
EIA**	NEMS	S. 2191 Core	1.02	1.1	NA
		S. 2191 Limited Alternative/ No International Offsets	1.23	1.63	NA
CATF	NEMS	S. 2191	NA	1.07	NA

* ACCF/NAM reports in the year 2014.
**EIA reports in the year 2020.
‡ Index constructed by using the EIA reported price of residential electricity in 2006 as 8.91 cents per kwh in 2006 dollars.

Table 8a: Change in Index of Gasoline Price (Index, 2005=1)

Group	Model	Scenario	Index 2015	Index 2030	Index 2050
MIT	EPPA	No Offsets, No CSS Subsidy	1.28	1.4	1.21
		15% Offsets	1.29	1.45	1.23
		CSS Subsidy	1.28	1.4	1.21
		15% Offsets, CSS Subsidy	1.29	1.45	0.12
ACCF/NAM*	NEMS	Low Cost	0.98	1.66	NA
		High Cost	1.3	2.3	NA
EPA**	ADAGE	S. 2191	NA	1.33	1.66
	IGEM		NA	NA	NA
EIA**	NEMS	S. 2191 Core	1.07	1.19	NA
		S. 2191 Limited Alternative/ No International Offsets	1.18	1.44	NA
CATF	NEMS	S. 2191	0.91	1.05	NA

* ACCF/NAM reports in the year 2014.
**EIA reports in the year 2020.
‡ Index constructed by using the EPA reported price of a gallon of gasoline in 2005 as $2.35 in 2005 dollars.

Table 9a: Change in Index of Natural Gas Price (Index, 2005=1)

Group	Model	Scenario	Index 2015	Index 2030	Index 2050
MIT	EPPA	No Offsets, No CSS Subsidy	1.14	1.97	1.87
		15% Offsets	1.15	2.12	1.98
		CSS Subsidy	1.13	1.57	1.65
		15% Offsets, CSS Subsidy	1.15	1.64	1.77
ACCF/NAM*	NEMS	Low Cost	1.63	3.33	NA
		High Cost	1.67	3.94	NA
EIA**	NEMS	S. 2191 Core	1.74	2.18	NA
		S. 2191 Limited Alternative/ No International Offsets	2.28	3.24	NA
CATF	NEMS	S. 2191	NA	1.03	NA

* ACCF/NAM reports in the year 2014.
**EIA reports in the year 2020
‡ Index constructed by using the EPA reported price of a tcf of natural gas in 2005 as $7.51 in 2005 dollars.
o Index constructed by using the CATF reported price of natural gas per MMBTU in 2006 as $13.80 in 2006 dollars.

Constructing the Index

Models estimate the price changes ofn gasoline, natural gas and electricity in one of two ways: one, the model may estimate a baseline price and the price under S. 2191, so that a percentage change in price caused by S. 2191 can be evaluated; two, the model may estimate a price and create an index based on a base price-typically the 2005 price. This allows readers to gauge what prices will be in the future compared to today.

These two kinds of estimates are not readily comparable without additional information. Since the models that present price change estimates as an index do not report the estimate of the future baseline price, it is not possible to calculate the percent change from the baseline caused by S. 2191. However, when studies report a predicted future price, an index can be constructed that does allow direct comparison.

For example, the EIA reports that the price of a gallon of gas in 2030 will be $2.95 in 2006 dollars. The EPA reports that the 2005 price of gasoline was $2.34 in 2005 dollars. Adjusting the EIA predicted price for inflation using the CPI, the predicted 2030 price is $2.88. Dividing the inflation-adjusted EIA predicted price by the EPA reported price of gasoline yields 1.23, meaning there will be a 23% increase in the price of gasoline from 2005 to 2030 under S. 2191.

Endnotes

1. See e.g., IPCC(2007), Stern (2007).
2. http://www.barackobama.com/pdf/issues/EnvironmentFactSheet.pdf
3. Carbon capture and sequestration (CCS) in particular.
4. See Lucas (1990).
5. http://www.ers.usda.gov/Publications/EIB23/
6. Of course, in equilibrium each consumer would change its consumption bundle to avoid being without food. This example is used to illustrate is just an illustration of the magnitude of the impact.
7. http://www.carlton.mercedescenter.com/portal/site/DWS72100/menuitem.2bd76a9308ae9c856a916a913aa13453/?vgnextoid=e4407aaeb9a3a110VgnVCM10000014174335RCRD
8. Note that estimated costs in Table 4 are in real (2005 $) terms. We also make an assumption that Mercedes does not go up in price faster than other goods.
9. http://www.piedmontcars.net/
10. We prefer to speak in terms of consumption since this measure allows us to make welfare calculations.
11. NRDC "Forecasts of the Economic Effects of Climate Change Legislation: What Can We Conclude?" www.nrdc.org/policy
12. "The most important finding is that, regardless of whether the study is a peer-reviewed academic or government analysis, or a non-peer reviewed industry-backed forecast, one prediction is the same: per capita household income (as measured by per capita gross domestic product, or GDP) will not decrease from today's levels. In fact, all of the projections forecast robust economic growth, despite the limits on global warming pollution contained in the CSA. … The studies do, however, differ in a very crucial way with respect to how they present their results: some give the impression that average household income will decrease from today's level (generally, these are the industry-backed studies), while others are careful to present their estimate more accurately as how much less a household's income is likely to grow as a result of the CSA."
13. We prefer to speak in terms of consumption since this measure allows us to make welfare calculations.
14. This amounts to reduction of emissions by 40% below its 1990 levels.
15. http://www.nrdc.org/legislation/factsheets/leg_07121101A.pdf
16. All dollar values are denominated in 2005 dollars.
17. H. R. 6 increases higher CAFE standards to 35 mpg and sets the minimum mpg at 27.5. The bill also increases production of renewable fuels from 4 billion to 36 billion gallons and increases efficiency standards on certain household appliances, light bulbs and electric motors.

18. All dollar amounts denominated in 2007 dollars.

19. These estimates of the price (and all resulting effects on GDP and prices of energy) are sensitive to the assumption that there is no banking of allowances. A study conducted by CRA International tested the effect of banking on allowance price and found that banking increases the price in the short run and decreases the price in the long run. CRA estimates that banking reduces the present value of the costs of S. 2191 by $100 billion. W. David Montgomery, *et al.*, "Economic Analysis of the Lieberman-Warner Climate Security Act of 2007 Using CRA's MRN-NEEM Model," CRA International (April 2008).

20. Denominated in 2007 dollars.

21. Applied Dynamic Analysis of the Global Economy (ADAGE) and Intertemporal General Equilibrium Model (IGEM).

22. Denominated in 2005 dollars.

23. The elasticity of the supply labor is higher for IGEM than for ADAGE, thus the GDP losses are larger for IGEM.

24. Denominated in 2006 dollars.

25. Such as the higher CAFE standards mandated in H.R. 6.

26. The estimates of the model are also sensitive to the number of different GHGs covered. Metcalf *et al.* find that by extending policy to cover more GHGs, the same reduction in total emissions can be achieved at a lower cost because abatement is less expensive for small amounts of reductions for many different gases. Metcalf, Gilbert E., *et al.*, "Analysis of U.S. Greenhouse Gas Tax Proposals," NBER Working Paper (April 2008).

27. Denominated in 2004 dollars.

28. If the price of an allowance ever rises above the TAP price, then the cap-and-trade system becomes essentially a tax on carbon emissions.

29. A summary of theDingell draft is available at proposal still in draft http://www.house.gov/dingell/carbonTaxSummary.shtml.

30. H.R. 3416; America's Energy Security Trust Fund Act of 2007.

31. H.R. 2069; Save Our Climate Act of 2007.

32. All dollar denominated in 2005 dollars.

33. Total GHG emissions includes the amount of CO_2 emitted plus all other GHG weighted by their potential effect on global warming.

34. See Nordhaus (2007), Weitzman (2007) for the discussion on this issue.

35. We do not even need the constant consumption growth assumption.

36. Note that we mean consumption per capita.

37. Stern (2007) assume $\sigma = 1$, while Lucas (1990) sets it to 2. We consider both values.

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