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Cost containment in climate policy and incentives for technology development

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Abstract Safety valves, discretionary advisory boards, and other cost containment mechanisms enhance the political feasibility of stringent climate policy by limiting firms' and households' exposures to higher than anticipated costs associated with reducing greenhouse-gas emissions. However, cost containment comes at a price; it increases the risk of climate-related damages and simultaneously discourages investments to develop low-carbon technologies. A stylized model of the cost of climate policy is used to estimate that proposed cost containment mechanisms will increase emissions by 11–70% by 2030. Because these clauses limit the payoffs to innovation, they reduce our societal capacity to affordably mitigate climate change through technology improvement. If cost containment measures are to be employed at levels discussed in recent policy debates, then complementary policies to fund technology development will be needed; crucially, the two also need to be linked. One way to resolve the impasse between increased climatic damages and reduced incentives for innovation is to create a technology development fund with contributions indexed to the amount by which the market price for carbon exceeds the price cap.

1 Introduction

Cost containment measures limit the macro-economic risks of complying with quantity based greenhouse gas (GhG) reduction targets by setting an upper limit on

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the price of carbon emissions. “Safety valves”, discretionary advisory boards, and other cost containment mechanisms make stringent climate policy more politically palatable by limiting investors’ and households’ exposure to higher than anticipated abatement costs. Many national and sub-national governments have proposed or enacted such mechanisms.

A primary justification for cost containment mechanisms is that they reduce the near-term price volatility of emissions permits in nascent cap-and-trade regimes. It is more difficult however to apply this justification to the wide array of recently proposed cost containment measures because of two characteristics. First, the *levels* of cost containment being proposed mean they almost certainly will become binding within a few years of initiating the cap-and-trade program. Second, the *duration* of proposed measures extends for decades, well beyond the period of possibly turbulent start-up conditions. These characteristics introduce two concerns. First, binding safety valves allow emissions to exceed emissions limits, increasing exposure to climatic damages. Second, these clauses place an upper bound on the payoffs to innovation in low-carbon technologies, reducing the potential for policy-induced technological change. How can the benefits of cost containment be maintained while avoiding the combination of excess climatic damages and reduced incentives for innovation?

In addressing this question, this study begins by examining the assumptions behind debates over the need for cost containment. A global survey of cost containment mechanisms in climate policy shows their prevalence. A simple model is then used to describe the effect of safety valves on incentives for innovation and on emissions. Finally, a mechanism for correcting for the reduced incentives for investments in technology development is introduced.

2 Debates about the need for cost containment

Divergence among underlying assumptions fuels vigorous debates about whether and how to implement cost containment for climate policy. This section outlines the characteristics of the policy instruments being discussed, identifies sources of disagreement, and discusses implications for incentives for investments in cost-reducing innovation.

2.1 Price-based and quantity-based pollution control

Uncertainties about future damages, and about future costs to avoid those damages, introduce a tradeoff in policy design. By imposing a tax, policy makers can set a limit on the economic costs of climate policy, while leaving future environmental damages unconstrained. Alternatively, by imposing a quantity-based constraint on the amount of pollution allowed, they can set firm limits on environmental damage, albeit with unknown future costs. If the costs of abatement are expected to rise steeply relative to damages, a price-based instrument is preferable so that the level can be set to avoid runaway costs. If the damages are expected to rise faster, then an emissions-based target can be used to set the level of emissions below the point at which damages rise to unacceptable levels. Choosing the correct instrument reduces the chances of making costly mistakes. Pervasive uncertainty, about both the carbon cycle and the ease with which we can transform the energy system, makes avoiding such mistakes important for climate policy. With both sources of uncertainty substantial, the optimal choice between the two depends on the relative slopes of the marginal damage and marginal cost curves (Weitzman 1974).

Both quantity and price targets have been proposed to address climate policy, as have designs that combine features of each. Cap-and-trade systems set quantity limits on emissions of greenhouse-gases and allow entities to buy and sell emissions permits. Under a carbon tax, a price based instrument, emitters pay the government an amount related to the amount of CO_2 they emit. 'Hybrid' instruments combine features of both types of policies (Pizer 2002). For example, a hybrid system might consist of a cap-and-trade system in which the government imposes an upper limit on the market price for pollution permits by agreeing to make additional permits available at a pre-specified price. A central feature is that the limit on emissions permit prices takes precedence over the quantity limit; once the price cap is reached the quantity limits are no longer binding.

2.2 Sources of disagreement over preferred policy instruments

Preferences for carbon taxes, cap-and-trade, or hybrids are attributable in part to differences in the following premises and objectives.

2.2.1 Non-linearities in abatement and damages

One source of the difference in preferences arises from expectations about whether we are more likely to encounter non-linearities in the costs of climate damages or in the costs of abatement. Are we mainly concerned that aspects of the climate system will manifest abrupt changes as a result of incremental additions of GhGs to the atmosphere? Or is the bigger worry that once inexpensive emissions reductions efforts are achieved, that further efforts to reduce emissions will impose rapidly escalating costs?

Note that the debate on hybrid instruments is asymmetric. In practice, proposed hybrid schemes include only quantity-based instruments with a constraint on cost; there are no proposals for price based instruments that explicitly include a limit on emissions—for example, a carbon tax that includes an emissions constraint that takes precedence over the level of the tax.[1] The absence of this policy option in policy debates may reflect expectations among policy makers that non-linearities in the costs of emissions reductions pose a greater risk than do abrupt changes to the climate system; alternatively it may simply reveal a higher priority placed on abatement costs than on damage costs.

2.2.2 Level of price cap relative to expected price

The extent to which a hybrid system act primarily as a price or a quantity based instrument depends on the level of the price cap relative to the expected cost of abatement (Jacoby and Ellerman 2004). Setting it low makes the scheme resemble a price instrument and setting it high makes it a quantity based instrument. Under a

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[1] Enabling Congress to periodically revisit the level of the tax allows for heightened emissions stringency (Metcalf 2009b), although if not explicitly specified, it also could reduce the level of the tax.

hybrid system, a second source of disagreement thus arises from perceptions of the difference between the level of the price cap and the expected price without a cap. If the cap is set at a level lower than the expected cost, then there may be genuine concern that environmental outcomes will fall well short of objectives. This concern is reduced considerably if the cap is set at a level that is close to a mean or upper bound of the expected price without a cap. Because most price cap proposals include dynamic mechanisms, both the choice of initial cap and the rate at which it escalates affect the merits of these arguments. Alternatively, given a policy proposing an initial price cap and escalation rate, disagreements about the attractiveness of a hybrid mechanism turn on expected abatement costs. For example, in a recent exchange Harvey (2007) says the cap "will be invoked rarely, if at all," whereas Krupp (2007) sees the cap price being reached as "a likely scenario," resulting in climatic damages that should be avoided.

2.2.3 Perceptions of political feasibility

Perceptions of the political feasibility of passing legislation also affect prescribed policy instruments (Felder and Schleiniger 2002; Bennear and Stavins 2007). For those that consider unconstrained prices under a cap and trade scheme politically infeasible, a price cap provides a way to overcome the concerns of affected interest groups (Pizer 2002; Hourcade and Ghersi 2002). Alternatively, others argue that governments may be willing to adopt stringent price-based climate policy, e.g. via revenue recycling, making price caps an unnecessarily distortionary concession (Nordhaus 2007; Victor and Cullenward 2007; Metcalf 2009a). Expectations about the strength and effectiveness of interest groups are highly uncertain and affect choice of optimal policies once political feasibility considerations are included.

2.2.4 Complementary mechanisms

The inclusion of other cost containment measures affects the strength of the case for safety valves. The ability to bank and borrow permits, reduces the near term price volatility making safety valves less necessary in achieving their short term anti-volatility objective. In contrast, the use of price caps in conjunction with price floors—also referred to as symmetric safety valves and price collars—avoids the adverse effects on investment in technology development that arise when using price caps alone (Philibert 2008; Fell and Morgenstern 2009).

2.2.5 Private vs. social costs

Support for safety valves may also be affected by concerns of the costs that climate policy might impose on individual firms or interest groups (Bovenberg et al. 2005). Given a quantity target, there are no additional costs that accrue to specific interest groups from the imposition of a safety valve, only cost savings for carbon intensive actors. Some of the disagreement may be affected by concerns about narrower private interests rather than about social welfare.

2.2.6 Near-term vs. longer-term objectives

Finally, differences arise based on whether safety valves are implemented in order to suppress near-term price volatility or the aggregate cost of abatement over the longer-term. Adverse effects on damage costs and investment incentives are greater in the latter case. The duration over which a safety valve is to be in place indicates which of these objectives policy makers are pursuing.

2.3 Inducing innovation under climatic uncertainty

Disagreements over the extent of the need for technological change also explain differences over cost containment. At the root of each of these debates over price, quantity, and hybrid instruments is the concern that stabilizing GhG concentrations will be painfully expensive. However, the costs of meeting emissions targets can be reduced through the development of new technologies, and the improvement of existing ones. Price signals, in the form of carbon prices, raise the cost of carbon-intensive energy technologies and make low-carbon alternatives more attractive as substitutes; the expected future demand for low-carbon technologies increases with the stringency of the policy, whether via an emissions constraint or a price (Nemet 2009). Investors in innovative low-carbon technologies will expect higher payoffs and thus increase their investment as expectations about the stringency of future policy rise. Climate policy can thus "induce" private sector efforts to invest in developing low-carbon technologies and thus can shift the marginal cost of abatement curve downward. Emissions fees provide an advantage over standards since they reward over-performance.

In dampening the volatility of expected future prices, a safety valve reduces the risk for future innovators since it will tend to make the size of the market for successful innovation less uncertain. Proponents of safety caps have argued that this feature of the safety valve actually provides *enhances* incentives for innovation (Jacoby and Ellerman 2004). However, the effect of the safety valve on expected future markets is asymmetric; it cuts off the upper tail of the distribution of expected profits, but not the lower. While, ceteris paribus, a narrower distribution of expected outcomes will encourage risk averse innovators to invest more, it will not increase investment if the narrowing of uncertainty is achieved entirely through the elimination of innovators' most profitable outcomes. In contrast, allowing banking of permits from one period to another provides a way to reduce carbon price volatility; it does so symmetrically because it eliminates price spikes due to temporary shortages, but raises prices in times of plenty because permits hold value in future periods. Depending on the level at which it is set, a price floor can provide symmetry as well (Burtraw et al. 2009).

3 Cost containment in proposed policies

Cost containment mechanisms feature prominently in national and sub-national efforts to regulate GhG emissions; no true cost-containment mechanism exists at the international level.

3.1 National

Several countries that have ratified the Kyoto Protocol (KP) include cost containment measures in their national implementation plans. The government of Canada, in order to secure industry support for KP ratification in 2002, agreed to sell permits for $C15/tCO_2$, so that industry would not pay carbon prices above that level. By

2006, growing acknowledgment that its emissions were accelerating led to Canada's announcement that it would not meet the 2012 goal and was abandoning the KP targets. With a more binding cap, Denmark imposed a penalty for firms that do not comply with its KP target of DKK40/tCO_2 (~\$8/tCO_2). New Zealand has discussed the possibility of using a cap to limit economic risk in its national implementation plan (Kerr 2007). Australia has been running an emissions trading pilot scheme in the province of New South Wales, where penalties for non-attainment are set at A\$12/tCO_2 (~\$11/tCO_2).

3.2 Sub-national

A variety of sub-national governments have announced plans to implement climate policies. Most consist of aspirational emissions reductions targets with little or no enforcement mechanisms and as a result, cost containment is less of a concern. For those with the most mature proposals, cost containment is high on the agenda. California's Global Warming Solutions Act (Assembly Bill 32), which the state's legislature passed in 2006, sets GhG reduction targets of 1990 levels by 2020 (Nunez 2006), and the accompanying Governor's Executive Order includes a 80% reduction target for 2050 (Schwarzenegger 2005). A "safety valve" clause gives the Governor discretion to waive the emissions reductions requirement in any year in case of "extraordinary circumstances, catastrophic events, or threat of significant economic harm" (Nunez 2006). Ten states in the Northeast U.S. have signed the Regional GhG Initiative (RGGI), which targets reductions of 10% by 2018. A recent version of this agreement includes a safety valve in the form of a "price trigger" of \$10/tCO_2, which increases at inflation plus 2% per year (RGGI 2007). When the price of emissions permits reaches this level, compliance is extended for 4 years and offsets can be used to satisfy targets.

3.3 U.S. federal policy

Cost containment has been central to federal efforts to regulate GhGs. As of mid-2009, the only limits on GhG emissions enacted by the federal government is its GhG emissions intensity target (tCO_2/\$GDP) announced in 2003. Costs were contained both by indexing the targeted reductions to economic growth and by making compliance voluntary. In 2008, a dozen bills establishing a federal climate policy were drafted or preliminarily discussed in the Congress.[2] Almost all contain some form of cost containment (Table 1). The proposed cost-containment measures come in a variety of forms.

- *Pre-specified price caps*: Two of the bills include language about the precise level at which the price of CO_2 emissions credits is set (H.R.1766 and Udall-Petri draft). These proposals also establish a rate of escalation, usually at some rate above the consumer price index.

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[2] The authors and bill numbers for these pieces of draft legislation include: Lieberman-Warner (S.2191), Bingaman-Specter (S.1766), McCain-Lieberman (S.280), Sanders-Boxer (S.309), Kerry-Snowe (S.485), Olver-Gilchrest (H.R.620), Waxman (H.R.1590), Udall-Petri (draft for discussion), Feinstein-Carper (S.317), Alexander-Lieberman (S.1198), Stark (H.R.2069), Larson (H.R.3416).

Table 1 Cost containment in climate bills discussed in the 110th U.S. Congress

Authors	Bill	Cost containment provisions
McCain-Lieberman	S.280	Borrowing for 5-year periods with interest
Sanders-Boxer	S.309	Price cap is set by cost of commercially available technologies
Feinstein-Carper	S.317	Borrowing for 5-year periods
Kerry-Snowe	S.485	Offsets
Alexander-Lieberman	S.1198	No provisions
Bingaman-Specter	S.1766	\$12/tCO$_2$ price cap, rising at 5%/yr above inflation
Lieberman-Warner	S.2191	Gives Carbon Market Efficiency Board discretion to specify cost containment
Olver-Gilchrest	H.R.620	Borrowing for 5-year periods with interest
Waxman	H.R.1590	No provisions
Stark	H.R.2069	\$3/tCO$_2$ tax rising by \$3 annually
Larson	H.R.3416	\$3/tCO$_2$ tax rising by inflation+10% annually
Udall-Petri	Draft	\$12/tCO$_2$ rising at 2–8%/yr above inflation

- *Discretionary price limits*: Two other bills include measures limiting prices but do not specify the level in advance (S.309 and S.2191). Similar to California's legislation, which gives the Governor authority to override the emissions targets, these bills give discretion to administrators to set limits on carbon prices.
- *Taxes*: Two bills implement cost containment inherently by specifying levels of carbon taxes that increase over time (H.R.2069 and H.R.3416).

Note that those bills that did *not* include cost containment provisions (S.485, S.1198, and H.R.1590) made very little progress through the legislative process. While none of the proposals in 2008 were passed, debates over implementation details influenced The American Clean Energy and Security Act (H.R. 2454) in the 111th Congress. The version of H.R. 2454 passed by the House of Representatives in June 2009 included a combination of discretionary and pre-specified price limits; use of offsets can be increased if needed and a 'strategic allowance reserve' can be drawn upon with an initial price level of \$28/tCO$_2$ in 2012.

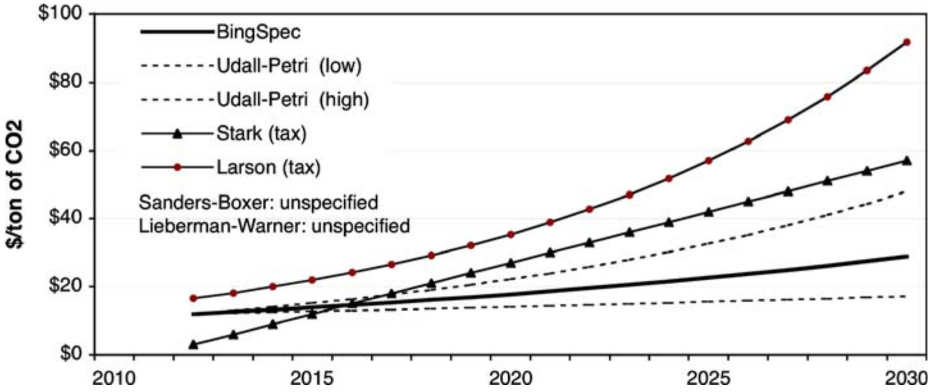

Fig. 1 Proposed cost containment measures in 110th Congress: upper limits on the price of CO$_2$ emissions

The proposed bills that fall in the first and third categories—those that specify an upper limit on the price of carbon emissions—vary considerably in both their near term price limit and that for 2030. The range of price caps for 2030 possible within this set of bills is \$17–92/tCO$_2$. Figure 1 shows the price limits which would be in effect through 2030 for the various bills with quantifiable cost containment measures.

4 Effect on investment incentives and emissions

Cost containment mechanisms limit the scope for cost-reducing technological change by reducing incentives for investments in developing low-carbon technologies. This section uses marginal abatement cost curves to show that some technology development projects will be abandoned due to cost containment mechanisms. It also estimates the scale of excess emissions and then simulates a mechanisms to address these two problems.

4.1 Marginal cost of emissions reduction

Analogous to a supply curve, a marginal abatement cost (MAC) curve relates GhG emissions reductions (q) that are available at each price level (p) at a given point in time. Figure 2 shows the effect of imposing a cost constraint on the price of emissions. A climate policy, such as those discussed above, might have a quantity target, q'. Meeting emissions reduction target q' implies a carbon price p'. A cost containment measure would limit the price of carbon emissions, such that the price for emissions permits cannot rise above p^*. As a result of the lower price, the economy will reduce emissions by q^* instead of q'. Because $p^* < p$', emissions will be larger under the price cap than they would be without the price cap. The amount $q' - q^*$ are emissions in excess of the quantity limit identified in the climate policy. This configuration creates a problem because even though the safety valve limits abatement costs,

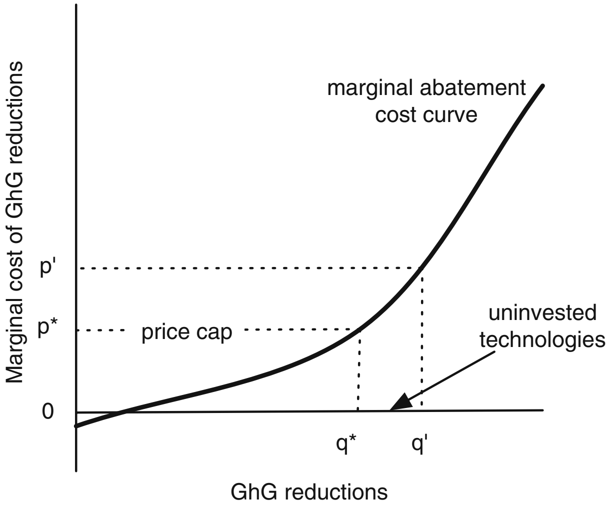

Fig. 2 A marginal abatement cost curve and the effect of cost containment measures on the price of GhG emissions. "Uninvested" technologies are those that would pay off at price levels between p' and p^*

climate damages, and in fact exacerbates damages by allowing higher emissions than would have occurred without the cap.

Technologies that would have avoided emissions $q' - q^*$ will not be deployed because they have costs above p^*. Moreover, nascent technologies that have the potential to be effective at costs between p^* and p', are not developed. Successful investments in these technologies would have lowered the right-hand side of the MAC curve, reducing p', for a given q'. In practical terms, there are technologies that are currently expensive, that would not be invested in if their expected costs are between p^* and p'. One might think of a technology such as carbon capture and sequestration (CCS) with current costs (>\$100/tCO$_2$) well in excess of any carbon prices currently being discussed (Anderson and Newell 2004), but with potential to be much cheaper (Rubin et al. 2007). A price cap on carbon that is an order of magnitude lower than the cost of reducing emissions using this technology will severely restrict the incentive for firms to build new coal plants, e.g. with gasification, which are amenable to capture and sequestration later, never mind investing in improving the CCS technology directly.

4.2 The climate innovation investment decision

Under proposed safety valve levels, innovators, who decide whether to make investments in innovation for low-carbon energy technologies, will under-invest. The payoffs to innovators' investments are affected by technical uncertainty, policy uncertainty, and appropriability, their ability to capture the value of their innovations. They decide whether to proceed with a project if the net present value of the revenues (R) equals or exceeds the costs (C). The expected revenues (R) decrease with the costs of production (P), increase with the government-imposed price of carbon (p'), and increase with the level of appropriability (α):

$$R = f(-P, p', \alpha) \tag{1}$$

The cost of the new technology is the sum of the R&D investment (D) required to develop the technology, and the sum of the costs involved in production.

$$C = D + P \tag{2}$$

Cost is determined by the success of the R&D program in creating costs savings (S) from the original production cost, P_o. The size of the cost savings is defined by an exogenous technical opportunity which the investing firm knows ex ante. The probability of achieving those savings is defined by a function (σ) and increases with the size of the R&D investment.

$$P = P_o - S\sigma D \tag{3}$$

The investment is made if revenue is equal to or exceeds costs:

$$f(P, p', \alpha) \geq P_o + D(1 - S\sigma) \tag{4}$$

If a price cap p^* is imposed such that $p' > p^*$, firms will make fewer investments in new technologies. The cap would reduce the incentives for investing in new technologies that might enable very large reductions in emissions, but whose costs are expected to be above the price cap. Figure 3 shows a quantitative example of the impact of a price cap on the market size of a carbon-free energy technology

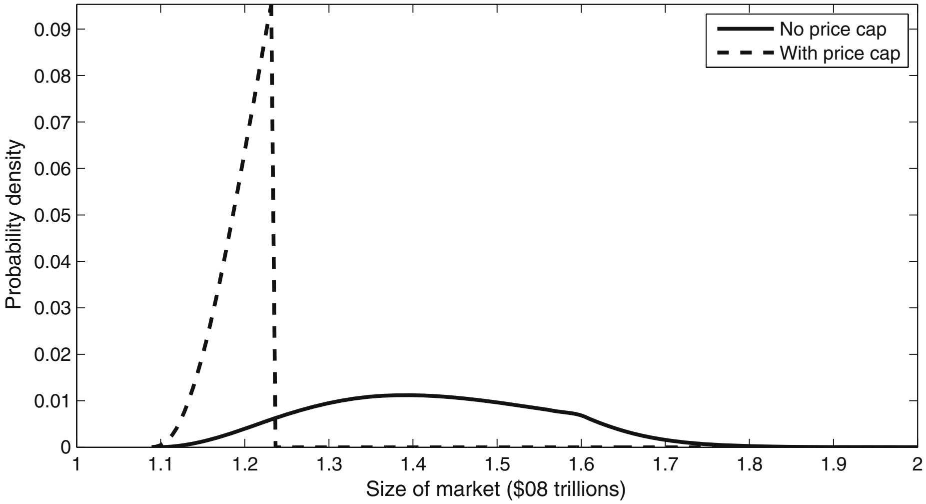

Fig. 3 Probability density function (PDF) showing the size of the market for a zero-carbon technology (trillions of current dollars) assuming a distribution of possible future carbon prices. The *solid line* shows the PDF of market size when no price cap is in place and the *dashed line* shows the PDF of market size with a price cap in place at \$29/tCO_2

(the Appendix includes detail on this example). One insight from this example is that price caps have a disproportionate effect in reducing the possibility of "big hits" that motivate risk seeking investors such as venture capitalists. Political economy considerations about the credibility of stringent future targets (Montgomery and Smith 2007) could be taken into account by defining the future price of carbon not simply as an exogenous choice by the government, but by political considerations, for example by society's willingness to pay to avoid climatic damages (W), such that $p' = f(W)$.

4.3 Estimating excess emissions

Proposed safety valves would cause climate policy to miss reduction targets by substantial amounts. The estimates calculated here using a highly stylized model derived from Intergovernmental Panel on Climate Change (IPCC) results, are similar to those in detailed modeling studies by the Energy Information Administration (EIA) and the Environmental Protection Agency (EPA).

4.3.1 IPCC meta-analysis

This analysis uses the costs of mitigation undertaken by the IPCC in its Fourth Assessment Report (IPCC 2007a, Section 11.3). The IPCC used the outputs of multiple integrated assessment models to estimate the potential for reducing GhG emissions in 2030 at four levels of carbon prices (see Table 2). These estimates provide the total GhG reductions available for which the marginal cost of abatement

Table 2 Range of economically available GhG emissions reductions available at various carbon prices

Carbon price ($/tCO$_2$)	Reductions (%) "bottom-up"	Reductions (%) "top-down"
$0	7–10%	none
$20	14–25%	13–27%
$50	20–38%	21–34%
$100	23–46%	25–38%

Survey of model results by the IPCC

is equal to or below each of the four CO_2 prices.[3] The mitigation potentials from Table 2 are plotted in Fig. 4 as a range of marginal abatement cost curves, showing the range of expected reductions available at various carbon prices.

Limits on CO_2 prices for 2030 are calculated using specifications in each of the four proposals with an explicit cost containment provision (Fig. 1). Quantity targets for 2030 are then estimated for those policies which include GhG reduction targets. These amounts are compared to the IPCC results using the example of S.1766 (Bingaman-Specter), the one proposal that explicitly specifies both emissions reductions levels and safety valve levels for 2030.[4] The goal of returning U.S. GhG emissions to 1990 levels by 2030 specified in S.1766 represents a 37% reduction from BAU levels. This quantity target and the safety valve level in S.1766 are compared to the IPCC range in Fig. 4. One can observe that the quantity target (vertical dashed line) does not intersect the IPCC range of emissions reduction possibilities below the price cap. The minimum cost of reducing emissions to the S.1766 quantity target is \$48/tCO_2, the upper end of the range is \$337/tCO_2, and the value using the midrange curve is \$125/tCO_2. Even for the least expensive MAC, the safety valve will be a binding constraint on the carbon price. At the safety valve level of $29, the IPCC MAC implies that we can expect reductions of 15% to 30% (midpoint 22%), well short of the quantity target of 37%. The result of a binding cap and excess emissions is robust to the full range of abatement cost curves; it is found in more detailed models as well.

4.3.2 EIA and EPA analyses

EIA and EPA both produce similar estimates of the level of excess emissions and the year at which the cap becomes binding. Using its National Energy Modeling System (NEMS) model, EIA projects that emissions under S. 1766 with a price cap in place will be approximately 26% higher in 2030 than in the case without a price cap (EIA 2008). Similarly the EPA's analysis of S. 1766 , using the models ADAGE

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[3] The models surveyed by the IPCC fall into one of two categories: "top-down" approaches use macro-economic models that characterize market feedbacks and "bottom up" approaches use models that explicitly characterize individual sectors of the economy and the technologies used within them.

[4] The IPCC economic potential figure are worldwide. Previous studies show that marginal abatement costs for 2030 are more expensive in the OECD than in the rest of the world (see for example Table 11.3 in IPCC 2007a). We thus treat this curve as a lower bound on the costs of making emissions reductions for the U.S.

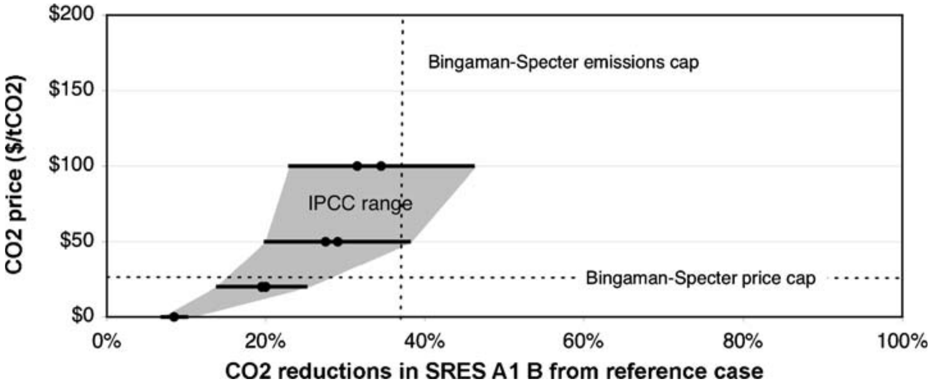

Fig. 4 Range of marginal abatement cost curves for 2030 using IPCC AR4 cost estimates. *Dashed lines* show emissions targets and safety valve level under S.1766 (Bingaman-Specter)

and IGEM, finds that emissions will be 23% above the cap when a price cap is in place (EPA 2008). The EIA forecasts that market prices will exceed the price cap in 2020 and that excess emissions will be 26% The EPA finds that market prices will exceed the price cap from the beginning of the program, even under the case where 10% of reductions can be achieved through purchasing international offsets. Table 3 compares the EIA and EPA results with this paper's analysis derived from IPCC MAC curves.[5] Compare excess emissions in 2030 of 23% by the EPA and 26% by the EIA to the 24% obtained using the midrange IPCC MAC curve. The year at which the cap is binding is slightly later using the IPCC MAC curve. Relative to these two models, the simple model developed in this analysis has lower marginal abatement costs in the early years, 2015–20 and higher abatement costs from 2030 onwards.

4.4 Climatic uncertainty and backstop technologies

The promising low carbon technologies that do not get invested in because of the price cap are a concern for two reasons. First, substantial uncertainties in the damages that will result from future emissions of GhGs exist and are heightened by the excess emissions described above. Increasing uncertainty emerges in surveys of expert judgement (Morgan and Keith 1995) and also in comparing the conclusions in the last two reports from the IPCC, cf. Houghton et al. (2001) and IPCC (2007b).[6] In addition, recent observations approach or exceed upper bounds of models, for example for the extent of arctic sea ice (Maslanik et al. 2007), emissions (Raupach et al. 2007; Sheehan 2008), and the fraction of GhG emissions remaining in the atmosphere (Canadell et al. 2007). Since climate damages result from the accumulated

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[5] The delayed crossover years are due to provisions for banking in the early years, which this analysis does not take in to account.

[6] The projected range of temperature change for 2100 in the Third Assessment Report was 1.4 to 5.8°C, while that reported in the Fourth Assessment Report was 1.1 to 6.4°C (Houghton et al. 2001; IPCC 2007b).

Table 3 Comparisons of future emissions and marginal abatement costs across models for a proposal targeting 37% reductions from BAU by 2030

	Year at which $p^* \geq p'$	Emissions above cap		MAC (\$/tCO$_2$)			
		2020	2030	2015	2020	2030	2050
IPCC (mid)	2023	–	24%	−6	11	125	483
IPCC (low)	2027	–	11%	−5	5	48	292
IPCC (high)	2019	3%	35%	−5	26	337	994
EIA	2020	5%	26%		≥ 15	≥ 25	
EPA	<2015	14%	23%	27–29	35–37	57–61	149–162

stock of GhGs in the atmosphere, exceeding an emissions target for a year or two is not a grave concern in itself. Continuously exceeding targets—as seen above—affects concentrations and contributes to increased damages.

Second, whether in the private or public sector, developing, commercializing, and deploying new energy technologies takes time; lags between policy-led price signals and sufficient technological diffusion to ameliorate environmental damages are difficult to shorten (Knapp 1999; O'Neill et al. 2003; Smil 2009). Further, technological change assumed in business-as-usual scenarios may grossly underestimate the magnitude of the changes to the energy system required (Pielke et al. 2008). Time lags combined with the possibility of higher than expected damages raises the value of having "backstop" technologies available, technologies that can provide additional emissions reductions, albeit at higher costs. With the possibility of high carbon prices eliminated, the private sector should not be expected to play a role in the development of backstop technologies.

4.5 Linking technology investment to price distortions

The weakening of incentives due to cost containment creates a need not only for complementary technology policy, but also for a mechanism that *links* the two. Because the size of the incentive-reducing effect of cost containment increases with the extent to which the price cap is binding, the magnitude of the complementary technology development efforts should be determined by the size of the distortion.[7] The more heavily we rely on a price cap to reduce the cost of climate policy, the more we need to invest in complementary policies.[8] The remedy proposed here is to (1) create a mitigation technology fund and (2) index contributions to that fund to the amount by which the market price for carbon exceeds the price cap.

The price cap benefits emitters by allowing them not to pay for the pollution they would have had to pay for if the original quantity limit were met. As Fig. 5 shows, the price cap restricts emissions reductions to level q^* instead of q'. The climatic damage that will be caused by the additional emissions, $q' - q^*$ is the amount society pays for the insurance against high abatement costs. In this proposed remedy the government

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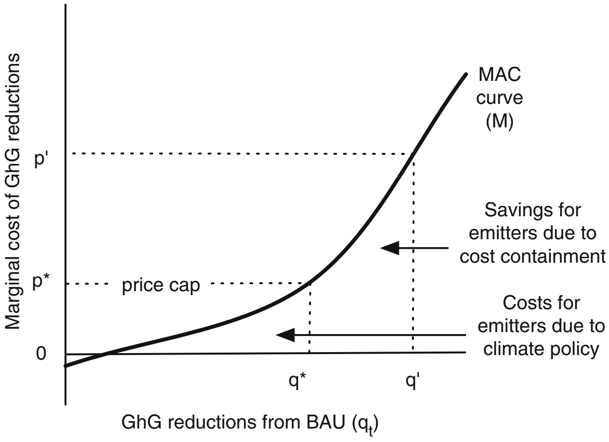
[7] A carbon tax set at a rate below the marginal damage cost would create a similar distortion. A tax set at a rate equal to marginal damages would not, although the aversion to the possibility of higher than expected damages might still justify additional incentives for technology innovation.

[8] The inclusion of renewable portfolio standards in recent proposals may reflect an acknowledgment of this issue, albeit not explicitly.

Fig. 5 Marginal abatement cost curve showing the effect of a price cap on the costs faced by emitters under a carbon constraint. The savings are the difference between the costs faced by emitters with and without a price cap



invests a portion of the payments for emissions credits that emitters avoid as a result of the safety valve. As a result of the cost reductions derived from the technology fund, the marginal abatement cost (MAC) curve would shift downward.

The following describes how this mechanism might work in practice. The price cap gets set exogenously at level p^*. Each year, the cap on emissions allowances (p') becomes more stringent. At some point, the marginal cost of abatement for that emissions reduction level increases to a point above p^*. In order for this mechanism to function, the cap-free emissions price, p' must be determined.[9] The abatement cost savings to emitters (σ) that result from the cost containment scheme are equal to the difference between the costs that emitters face with a price cap in place and without one.

$$\sigma_t = \int_{q^*}^{q'} M(q_t)\, dq \tag{5}$$

where M is the marginal abatement cost function and q_t is the actual level of emissions reductions. A blunt proposal is to devote a fixed percentage of the cost savings (β) as an annual contribution toward the technology and adaptation fund (F):

$$F_t = \beta \sigma_t \tag{6}$$

Firms will already be paying the government $(q' - q^*)p^*$ to purchase permits at the safety valve price, so provided p^* is not set extremely low, i.e. $\beta\sigma_t \leq (q' - q^*)p^*$, F could be obtained from those revenues. The benefits of the program will be a result of the productivity of R&D in reducing the marginal cost of abatement M as a result

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[9] Price discovery is an important challenge and might be accomplished using shadow prices of demonstration markets or prices from other countries without price caps. The issue is similar to that of defining a business-as-usual case from which reductions are compared; assumptions are needed.

Table 4 Policy simulation results for 2030

	1 Price at qty. cap (\$/tCO$_2$)	2 Reductions at price cap (%)	3 Excess emissions (GT CO$_2$)	4 Savings to emitters (\$b)	5 Contribution to tech. fund (\$b)
Bingaman-Specter (S.1766): −37% from BAU by 2030					
Low MAC	48	−30	0.5	21	2
Mid MAC	125	−22	1.2	78	8
High MAC	337	−15	1.7	281	28
Warner-Lieberman (S.2191): −50% from BAU by 2030					
Low MAC	124	−30	1.6	106	11
Mid MAC	240	−22	2.2	261	26
High MAC	548	−15	2.8	724	72

Assumes a price cap for carbon permits of \$29/tCO$_2$ in 2030

of investments, F. This fund only corrects for the distortions created by the price cap; there almost certainly will be reasons for the government to invest in technology in excess of F to correct for knowledge spillovers.[10]

Simulations were run from 2010 to 2030 to examine the effect of a price cap on emissions, carbon prices and the financial impact to emitters (Table 4). These results are for 2030, at which point the price cap used (S.1796) will have risen to \$29/tCO$_2$. To show the effect of the emissions cap, the results for two quantity-based emissions targets for 2030, −37% from BAU (S.1796) and −50% from BAU (S.2191), are presented. Results using midpoint, high and low values for the stylized marginal abatement cost curve are presented. Column 1 shows the marginal price for carbon permits (p') if emissions were reduced to the quantity limit (q') in the absence of a price cap. The substantial dispersion in values is a function of uncertainty in the MAC curve. Column 2 shows the emissions reductions from BAU that would be expected if the price cap (p^*) is introduced. The difference between the values in column 2 and the specified emissions limits in each of the bills leads to "excess emissions" ($q' - q^*$) which are shown in column 3. These are emissions that would not be allowed under the quantity cap but which are allowed if the price cap is in place. Emissions under S.1796 will exceed targets by 11–35% and under S.2191 by 40–70% because S.2191 has a more stringent target; the full range is thus described as 11–70%. Emitters benefit financially from the price cap because they do not have to pay for these excess emissions. These annual "savings" (σ) are shown in Column 4. The savings in 2030 alone range from tens of billions to hundreds of billions of dollars. Column 5 shows the contributions (F) that would be made to a technology development fund

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[10] A proposed Technology Accelerator Payment (TAP) in S.1766, captures many of the benefits of the mechanism proposed here. It allows emitters to purchase excess emissions at the price cap and devotes the revenues from those sales to technology programs. However, because the TAP does not take into account how expensive excess emissions reductions may be, it may under-estimate the amount of investment required. The size of the technology investment required depends not only on the amount of excess emissions but also on the magnitude of cost reductions needed in the technology development program ($p' - p^*$ from Fig. 2).

if 10% of the emitters' savings are dedicated to it ($\beta = 0.1$). For comparison, U.S. federal energy R&D has averaged less than $4b over the past two decades (Nemet and Kammen 2007).

While this proposal for a technology fund corrects for the distortions created by a price cap, it also introduces additional issues; the effectiveness of the fund in reducing abatement costs depends on good management, sufficient institutional capacity to assess technological alternatives ex ante, and the ability to interpret whether programs that do not achieve their technical goals represent poor choices or worthwhile failures. All of these decisions will need to be made amidst interest group pressure and inevitable competing social priorities. These issues raise the question of whether the best response to the disincentives created by safety valves is to add complexity to an already complicated piece of legislation, as is proposed here, or to adopt a completely different approach to climate policy (Prins and Rayner 2007). An assumption underlying this proposal is that the sum of the problems arising from shifting a substantial portion of technological decision making from the private sector to the public sector amounts to less of a concern than do the disincentives created by limiting payoffs to private sector innovators.

5 Summary

Cost containment mechanisms can limit exposure to the real risk of near term price volatility under nascent cap and trade schemes. But setting cost containment mechanisms at low levels and putting them in place for many years, introduces substantial environmental risk while discouraging innovation. Simulations produced by the stylized model introduced here show that proposed cost containment measures would increase emissions by between 11 and 70%. Because they occur year after year, they will introduce additional climatic damages. At the same time, cost containment reduces the incentives for innovation in low-carbon technologies by eliminating the most profitable payoffs. One should not expect a regime of nominally stringent, but avoidable targets to stimulate investment in technologies that only pay off at high carbon prices. Relying on 'contained' price signals as the primary source of incentives for innovation limits our ability to lower abatement costs through technological change; it particularly affects our ability to reduce emissions later, should damages become more severe than anticipated. Resolving this impasse between higher future damages and weakened incentives will require an alternative mechanism to correct for underinvestment. A technology development fund that is linked to the price cap provides a means by which to retain our ability to mitigate climate change while retaining insurance against high costs.

Appendix A: Example of a technology investment decision

As a concrete example of the reduced incentives for investment discussed in Section 4.2, consider a firm developing a low-cost carbon-free energy technology, which if successful, will produce electricity for 3 cents per kilowatt hour while emitting no GhGs. The size of the energy demand in exajoules for such a technology in 2030 is estimated here using runs on an integrated assessment model, MiniCAM, at

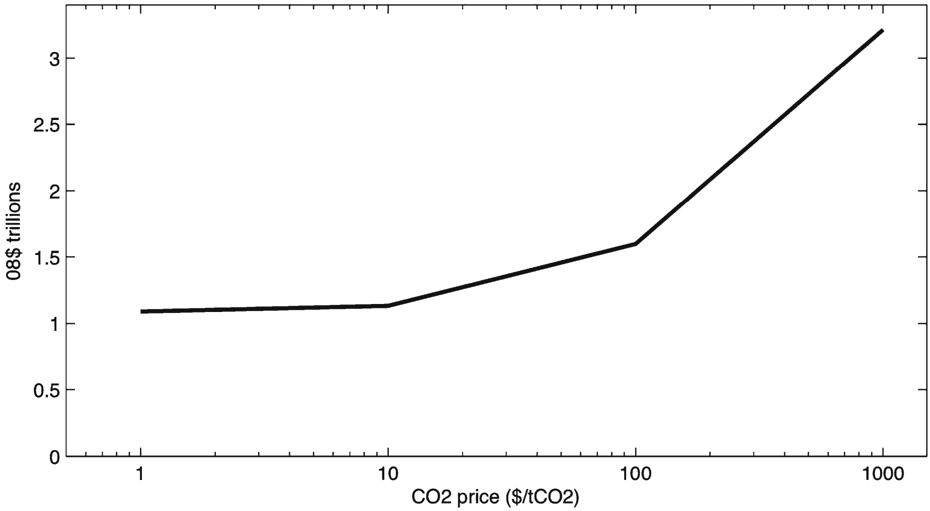

Fig. 6 Size of the market in 2030 for a zero-carbon technology with a levelized cost of 3c/kWh (trillions of current dollars). Note that this demand might be satisfied over many years. A log scale is used on the horizontal axis to show detail

various carbon prices (Edmonds et al. 2004).[11] Demand in exajoules is converted to installed capacity in terawatts assuming a capacity factor of 18.3%, such as would be appropriate for low-cost organic photovoltaics (PV). While the demand being met is in 2030, it may take several years to install technology sufficient to meet this demand. The capital cost for a PV technology producing energy for 3c/kWh is calculated as $0.35/W (Nemet and Baker 2009). The value of the market for this technology, spread over several years, is the product of the capital cost and the installed capacity discounted at 5% per year. The resulting values of the market size for a 3c/kWh carbon-free energy technology range from 1.1 to 3.2 trillion, increasing with the price of carbon (Fig. 6).

Investors funding the development of such a technology do so knowing that (1) the technical viability of the technology is inherently uncertain, (2) it will take many years to bring the technology to market, and (3) the price of carbon at that time is unknown. They make investment decisions based on the size of the future payoffs, which depend primarily on the market opportunity for this new technology. Here, they make the assumption that the expected carbon price in 2030 follows a distribution with a mode of $60/tCO$_2$ (EPA 2008). The distribution of possible future carbon prices looks dramatically different depending upon whether there is a price cap in place or not, since the price cap eliminates the possibility of carbon prices above the cap. The price cap used in this example is $29/tCO$_2$. A probability density

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[11] The following assumptions were used in the MiniCAM runs: advanced nuclear technology is available, carbon capture and sequestration is not available, and costless storage technology to account for intermittence of renewables is available.

function (PDF) for the expected market sizes shown in Fig. 6 is calculated using the distribution of future carbon prices and the market sizes at each price. Figure 3 shows the PDF of market sizes with and without a price cap.

Under this set of assumptions, the expected market value with the price cap in place is \$1.20 trillion and without the price cap is \$1.47 trillion. Investors with a large appetite for risk may also be affected by the difference in upper bounds: the upper 95th percentile value without a cap is 40% higher than when the cap is in place. Note that the size of the difference in the market size with and without price caps is sensitive to the level of the cap, uncertainty around the expected carbon price, and especially to the shape of the curve in Fig. 6. In this example, payoffs rise sharply at CO_2 prices above \$100/tCO_2, which in this case has a low probability. This feature is an artifact of the assumption in MiniCAM that advanced nuclear technology is available to satisfy large amounts of demand for low carbon energy. A situation in which the kink in the market size curve occurs closer to the expected carbon price would reveal larger differences in market sizes with and without price caps. Nevertheless, even in this case, investment decisions on the margin that would payoff without price caps, would not pay off with price caps in place.

The calculations in this appendix use several assumptions. With no price cap, the distribution for possible CO_2 prices in 2030 follows a gamma distribution with a mode at \$60/tCO_2 (see the upper panel of Fig. 7). This modal value is the midrange of expected carbon prices estimated by the (EPA 2008) in 2030. The probability density function uses the values $k = 4$ and $\theta = 20$. Without a price cap, the same distribution is used, but probabilities at CO_2 prices above the price cap take the value zero (lower panel of Fig. 7). Probabilities of prices below the price cap are scaled up proportionately.

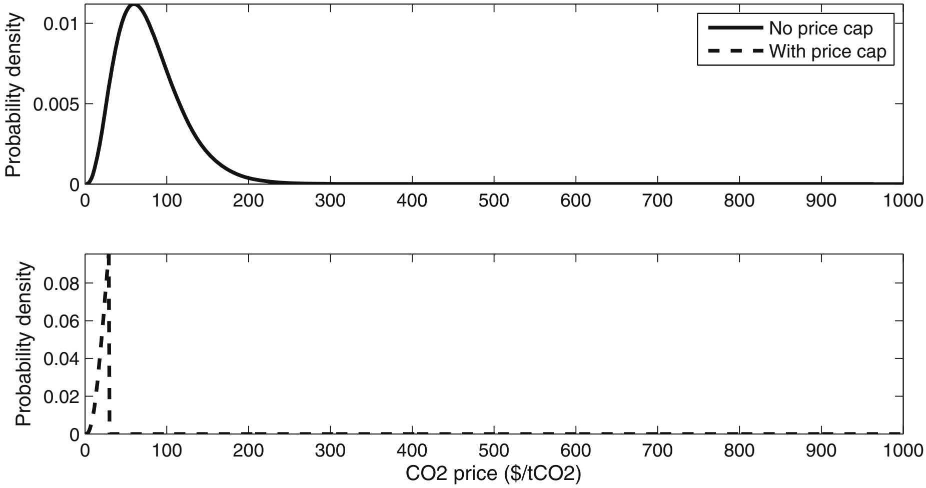

Fig. 7 Assumed distribution of possible CO_2 prices in 2030 with (*lower panel*) and without price caps (*upper panel*)

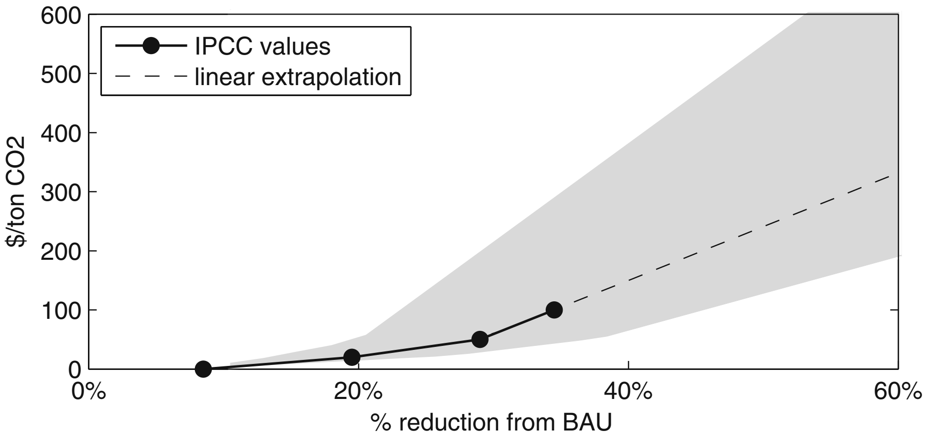

Fig. 8 Marginal abatement cost curves derived from IPCC values

Appendix B: Simulations of a linking mechanism

Because the objective is to understand the sensitivity of emissions and prices to the level of the price cap, this paper intentionally uses a quantity-based limit and cost containment mechanism from two separate bills discussed in the U.S. Congress. As a result, this analysis is not intended to analyze any specific policy. The full range of estimates from the IPCC is used to assemble marginal abatement cost curves (Fig. 8). It is important to note that this range fully encapsulates the assumptions on emissions abatement costs under the analyses by the EPA and EIA discussed earlier.

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