Can Options for Cost Containment Raise Costs?

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Abstract

Recent proposals for greenhouse gas (GHG) cap-and-trade systems have included allowances reserves as one mechanism among many aimed at "cost containment." Reserve designs can affect cap stringency depending on the source of allowances used to fill the reserve, although such decisions are often not explicit. Because of this potential impact on cap stringency, tradeoffs between costs and emissions are inevitable. Consequently, a reserve designed to avoid increases in emissions can raise not only total costs, but allowance marginal costs and allowance prices.

The design of California's GHG cap-and-trade system illustrates the tradeoffs that emerge when using an allowance reserve. The system has a reserve policy that includes an allowance reserve combined relaxation of limits on offset use. Under many scenarios, we find that this reserve policy raises expected total costs, marginal costs and allowance prices, while lowering expected emissions. Given the tradeoff between emissions and costs, however, the welfare consequences are ambiguous. Analysis of policy options finds that alternative reserves designs can achieve outcomes with lower expected prices and costs, while maintaining environmental integrity.

JEL: L51, Q52, Q54, H23

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I. Introduction

In recent efforts to design and implement cap-and-trade systems, particularly for greenhouse gas (GHG) emissions, "cost containment" has become a critical issue for addressing the program's economic impacts. Cost containment encompasses a suite of provisions aimed at mitigating the cost of achieving emission reductions, such as allowance borrowing and banking, use of credits for emission reductions made outside of the cap ("offsets"), longer (multi-year) compliance periods, price caps (and floors), and, most recently, allowance reserves. While the design of cost containment mechanisms has received much attention, less recognized is the potential for certain cost containment measures to potentially *raise* costs. An example of such a mechanism is an allowance reserve.[1]

An allowance reserve, like a price cap (or "safety valve"), lowers costs by relaxing emission targets when the marginal cost of emission reductions is high.[2] Many recent proposals for GHG cap-and-trade systems have included allowance reserves in lieu of a price cap, including California's GHG trading system, due to go into effect in 2013.[3] Allowance reserves have been introduced to address certain concerns with a safety valve. In particular, some have raise the concern that a price cap could lead to excess emissions, because it would introduce enough new allowances to the market to keep prices from rising above the predetermined trigger price.[4] Given the potential for an unlimited supply of allowances to enter the market, some see this as risking the integrity of the program's emissions targets. A related

[1] Other examples include a price collar, which combines a price floor and price cap.

[2] By relaxing the emissions cap when the marginal cost of emission reductions exceeds marginal benefits, both mechanisms can increase the efficiency of a cap-and-trade policy given uncertainty over future costs. Murray, Newell and Pizer, 2008; Fell et al., 2010.

[3] In addition, the most recent congressional attempts at comprehensive climate policy included allowance reserves (e.g., the Waxman-Markey bill, American Clean Energy and Security Act (HR 2454).)

[4] In fact, an allowance reserve can effectively achieve the same unlimited supply of allowances as a price cap if the reserve is continuously replenished with allowances, potentially from emission reductions made outside the cap – that is, offsets. Under some proposals, reserve allowances are released based upon criteria and conditions determined by a market committee based upon its assessment of market conditions, program performance, and potentially other factors. The discussion of allowance reserves in this paper assumes that reserves are released based upon *predetermined* price triggers (or other conditions.)

concern is that the safety value will lead to excessive allowance banking which may limit regulator's flexibility to increase the cap's stringency in future years given new information about costs or benefits.[5]

An allowance reserve can mitigate these perceived risks in two ways. First, the quantity of allowances provided by an allowance reserve can be limited to a finite quantity by establishing a reserve of fixed size at the outset of a program. Thus, a reserve can limit the supply of new allowances, and provide regulators with more discretion to shape supply and demand in future years.[6] Second, allowances used to fill the reserve can be taken from specific sources (or budgets) that ensure that net emissions do not increase.[7]

However, neither of these alternatives fully avoid an inevitable tension between the desire to limit emissions – often expressed as a concern about environmental "integrity" – and the desire to "contain" costs. For example, consider a "strict" definition of environmental integrity in which emissions can never exceed predetermined targets. In this case, the allowance reserve would need to be filled with allowances from under the cap. Because of the resulting one-for-one increase in cap stringency, the reserve would provide no cost mitigation; the reserve increases cap stringency when costs are low, but provides no flexibility when costs are high. Thus, policymakers must consider either relaxing this criteria of "strict" environmental integrity, or creating a "reserve policy" that combines an allowance reserve with other measures aimed at mitigating costs. For example, an allowance reserve could be combined with a policy that relaxes limits on the use of emission offsets. Under these circumstances, the consequences for costs and emissions would depend on the particular details of any "package" of mechanisms.[8]

Section II of this paper provides some basic observations about this tradeoff between costs and emissions as they relate to the design of an allowance reserve. These design choices raise several issues. First, neither the goals of cost containment nor the criteria for environmental performance (to be maintained when designing cost containment) are uniquely defined. Should cost containment policies aim to lower costs on average (e.g., lower expected costs)? Or, should cost containment attempt only to lower prices under high cost/high price market conditions? Likewise, can emissions ever be allowed to

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[5] Murray, Newell and Pizer, 2008. Stocking (2010) finds that a small number of firms with a large compliance obligation could buy allowances from a reserve at above market prices with the intent of lowering equilibrium market prices and thereby reducing their total compliance cost.

[6] These concerns can be mitigated by having trigger prices increase as more allowances are purchased. With a sufficiently large (or inexhaustible) reserve, market prices default to an administratively determined price curve when prices rise above certain levels.

[7] In principle, a price cap could also avoid increased emissions by borrowing allowances from future compliance periods.

[8] For example, *see* Fell et al, 2010. Of course, these policies aimed at mitigating costs may introduce other tradeoffs, such as concerns about the additionality of emission reductions associated with offsets.

exceed pre-determined caps? As we show, the choice of criteria have potentially important implications for reserve design and the resulting environmental and economic outcomes. Second, because an allowance reserve introduces tradeoffs between costs and benefits, the economic and environmental consequences of an allowance reserve policy depends on design details such as the sources of allowances used to fill the reserve and the cost-mitigating policies that are combined with the reserve.

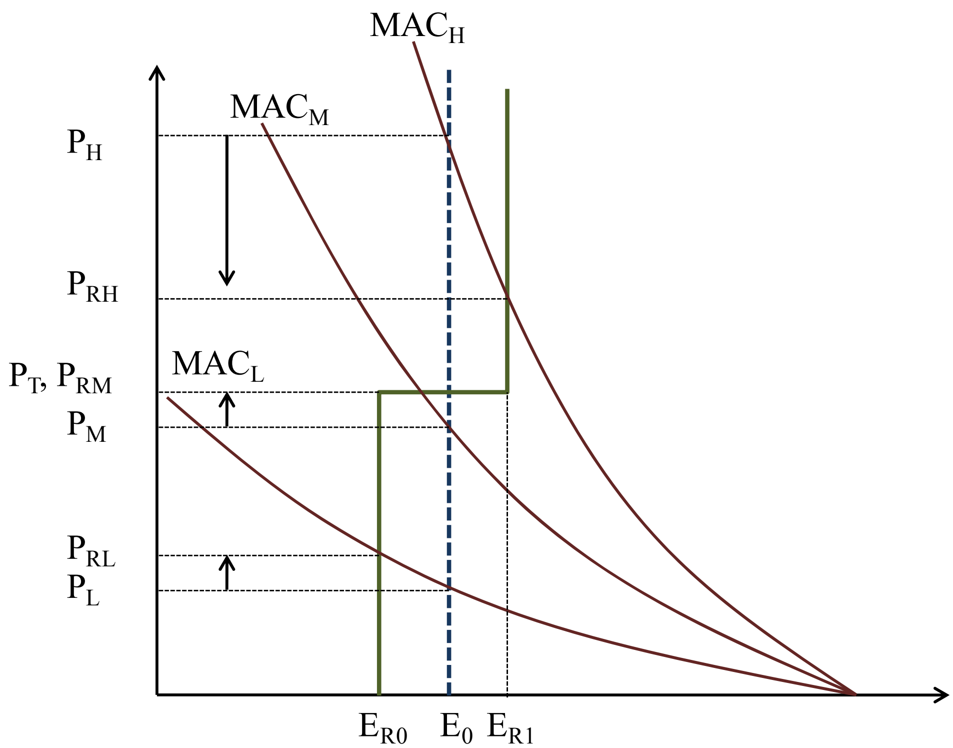
Section III of the paper analyzes the California's GHG cap-and-trade system – the first cap-and-trade system to utilize an allowance reserve – to understand these tradeoffs in practice. The design of this reserve reflects a particular balance between emissions and costs: the reserve is filled with allowances from allowance budgets to be used for compliance, thus increasing cap stringency, while rules limiting offset use are relaxed to help lower costs. Although the relaxation in offset use is intended to offset any cost impacts from greater cap stringency, the analysis shows that, under many reasonable assumptions, the California allowance reserve raises expected costs and lowers expected emissions. We also find that alternative reserve designs lead to outcomes that reduce expected costs, with expected emissions still greater than those without the reserve.

II. Market Outcomes with an Allowance Reserve

A cap-and-trade system provides the market with a supply of allowances and requires that regulated entities achieve compliance by surrendering allowances equal to their actual emissions. As illustrated in Figure 1, with an emissions cap, the supply of allowances is set at a constant, predetermined level, E_0. By contrast, an allowance reserve effectively creates a system with two emission caps, E_{R0}, and E_{R1}, with the allowance reserve equal to the difference between these caps, $R = \Delta E = E_{R1} - E_{R0}$.[9] Allowances are released from the reserve, through sale or distribution, when prices reach a predetermined trigger, P_T. As shown in Figure 1, the emissions cap without the reserve (E_0) is not necessarily the same as either the initial or final emissions caps with an allowance reserve (E_{R0} or E_{R1}). Abatement costs will depend upon unknown technology and market outcomes: Figure 1 illustrates this uncertainty through alternative abatement cost curves, MAC_L, MAC_M, and MAC_H , which correspond to allowance prices, P_L, P_M, P_H, with the price cap and P_{RL}, P_{RM} and P_{RH} with the allowance reserve.

[9] In many real world circumstances, where policymakers may not explicitly identify emission caps under alternative cap-and-trade system design, these alternatives emission targets may be ambiguous. In fact, some assessments of allowance reserves leave this issue ambiguous by defining the emission caps implemented with a reserve by terms such as "minimally acceptable cap" and "aspirational cap" that appear to peg caps relative to the stringency of an implicit fixed cap. For example, *see* Maniloff and Murray (2009). As this analysis shows, the ability of an allowance reserve to provide cost containment depends upon a comparison between emission targets with the reserve and those targets that would prevail without the reserve. Consequently, such comparisons can be important.

Figure 1
Emission Control Market Equilibrium with and without Allowance Reserve



As shown in Figure 1, the introduction of an allowance reserve changes both the quantity of emission reductions and the resulting costs and allowance prices. Assuming that E_{R0} and E_{R1} are bounded by E_0 (i.e., $E_o \in [E_{RO}, E_{R1}]$), it immediately follows that:

1. When equilibrium marginal costs (prices) without the reserve (*P*) are below reserve price triggers (i.e., $P < P_T$), an allowance reserve raises prices (marginal costs) and total costs (*T*) and reduces emissions (*E*) (or, it has no effect on these outcomes); that is, $P_R \geq P_0$, $TC_R \geq TC_0$ and $E_R \leq E_0$; and

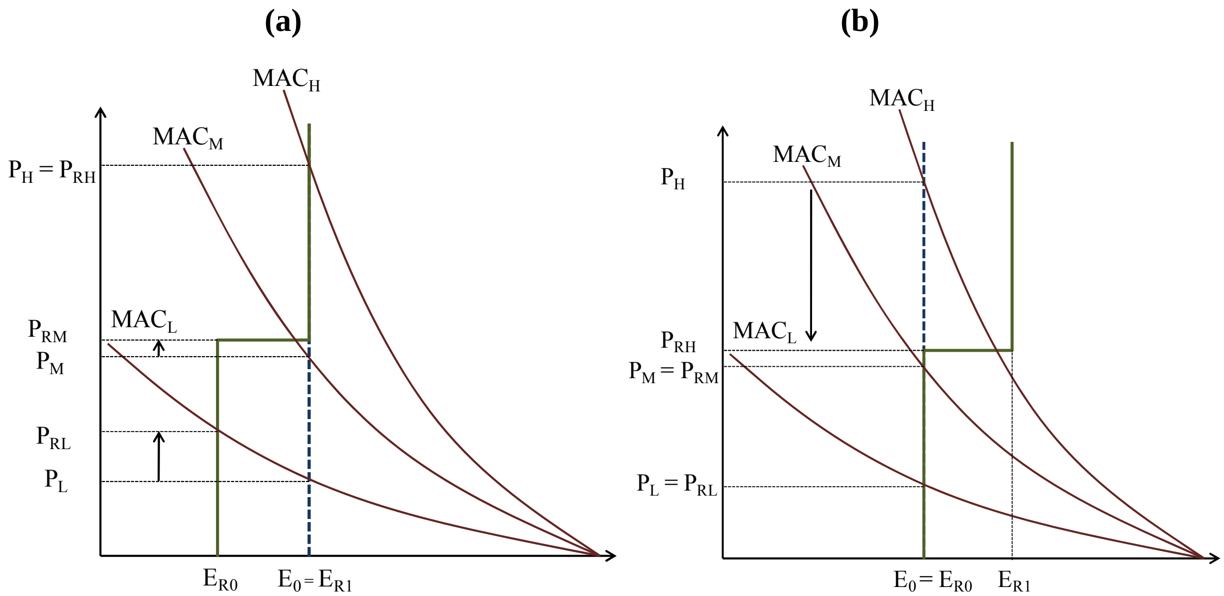
2. When costs are above reserve triggers, an allowance reserve reduces prices (marginal costs) and total costs and raises emissions (or, it has no effect on these outcomes); that is, $P_R \leq P_0$, $TC_R \leq TC_0$ and $E_R \geq E_0$

Consequently, an allowance reserve introduces a tradeoff between costs and emissions that depends on whether equilibrium prices are above or below the trigger price. This tradeoff is bounded by two extremes, as illustrated in Figure 2.[10] On the one hand, Figure 2(a) illustrates a reserve subject to "strict"

[10] Note that, with a safety valve, there is only one emission cap, and consequently it is a natural choice to set the emission caps with and without the safety value at the same level. However, from a negotiating standpoint, one might imagine that the cap might be set at different levels, such that expected emissions were set equal. This is the same spirit in which Fell et al. (2010) hold expected emissions constant when evaluating alternative hard and soft price collars.

environmental integrity criteria, such that $E_0 = E_{R1}$. Under this criteria, emissions cannot exceed pre-determined targets under any circumstances and the reserve is filled from allowances under the emission cap.[11] As should be immediately apparent, an allowance reserve will do little to contain costs under these circumstances – marginal costs are higher (and emissions lower) when prices are below price triggers, and marginal costs (and emissions) are unchanged when prices are above price triggers. At the other extreme, Figure 2(b) illustrates a reserve filled with "free" allowances, which results in higher emissions if allowances are released from the reserve, but does not raise costs (and prices) when prices are below the trigger price.

Figure 2
Emission Control Market Equilibrium with and without Allowance Reserve:
(a) Strict Environmental Integrity and (b) Reduced Cap Stringency



While a reserve can be welfare improving by allowing cap stringency to adjust given the actual level of costs, it is often proposed as a mechanism to help "contain" costs. However, criteria for "cost containment" are often not well defined. One criteria might be a reduction in prices (marginal costs) when marginal abatement costs are high. Under this objective, a cost containment provision would succeed if prices were reduced when MAC are high (i.e., MAC_H in Figure 1) even if the policy raises prices under other market circumstances (e.g., MAC_L or MAC_M). However, such a policy might raise *expected* marginal or total costs, because costs would increase under certain market outcomes (i.e., when prices are low) depending on the extent to which the reserve if filled with allowances from under the cap.

[11] The alternative in which the reserve is filled from emission reductions outside the cap (i.e., offsets) is discussed below.

Another criteria might be a reduction in expected marginal costs and/or expected total costs – that is, $E\{P_R|E_{R0}, E_{r1}\} < E\{P_0\}$ and/or $E\{TC_R|E_{R0}, E_{r1}\} < E\{TC_0\}$. Under this criteria, the choice of E_{R0} and E_{R1} directly affects the expected reduction in costs, contingent on the distribution of market outcomes: $\Delta E\{P\} = E\{P_R|E_{R0}, E_{r1}\} - E\{P_0\}$. In general, the introduction of an allowance reserve has ambiguous consequences for expected prices (marginal costs), expected total costs, and expected emissions given uncertainty about factors affecting costs (e.g., baseline emissions, MACs) and the choice of emission targets (E_0, E_{R0} and E_{R1}).[12] Moreover, this criteria could be modified to place greater weight on higher cost outcomes (relative to lower cost outcomes), consistent with risk-averse preferences or non-linear general equilibrium effects.

In practice, the choice of E_{R0} and E_{R1} is implicit in decisions about the "source" of allowances used to fill the reserve. Setting $E_{RO} = E_0$ reflects a decision to fill the reserve by relaxing cap stringency (when costs are high), while setting $E_{R1} = E_0$ reflects a decision to fill the reserve from allowances under the cap. Likewise, $E_{RO} < E_0$ (and therefore $E_{R1} > E_0$) reflects the decision to fill the reserve from a combination of allowances under the cap and potential increases in emissions. Other options for filling the reserve, such as offset purchases or borrowing from future periods, would also affect cap stringency, although through less direct means.[13]

Other important reserve design issues can also affect these cost-emission tradeoffs, including the size of the reserve and whether and how to replenish the reserve. While a larger reserve will provide more price mitigation in the event of unexpectedly high costs, it also magnifies the tradeoff between costs and emissions. Replenishing the reserve as it becomes exhausted offers the opportunity to reduce the initial reserve size, and thus can diminish the tension between costs and emission reductions. With replenishment, additional allowances are added to the reserve as allowances are released to mitigate prices. Allowances used to replenish the reserve could come from a number of sources, including future compliance periods, emission reductions outside the cap (i.e., offsets), relaxing the cap's stringency, or some combination of these alternatives.

One way to mitigate these tradeoffs is to combine a reserve with other measures aimed at lowering costs, such as relaxing limits on offset use. Such a combined "reserve policy" can reduce costs, while still maintaining environmental integrity, so long as measures to reduce costs are sufficiently large.

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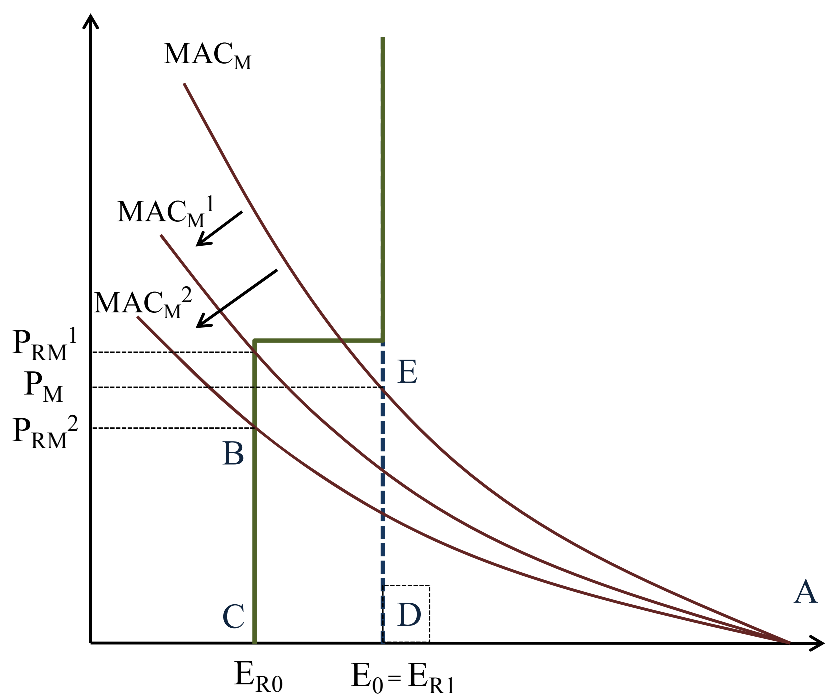
[12] Two exceptions are the two extremes illustrated in Figure 2. That is, under strict environmental integrity (Figure 2), expected marginal costs (prices), total costs and emissions are greater with the allowance reserve than without it; that is, E[P_R] > E[P_0], E[TC_R] > E[TC_0] and E[E_R] < E[E_0]. Likewise, under reduced cap stringency, expected marginal costs (prices), total costs and emissions are lower with the allowance reserve than without it.

[13] Borrowing increases the stringency of cap's in future periods, while offset purchases requires that additional emissions reductions be undertaken, albeit emission reductions achieved outside the cap.

As shown in Figure 3, when the cost-mitigation measures reduce the MAC from MAC_M to $MAC_M{}^2$, the reserve policy shifts equilibrium prices from P_M to $P_M{}^2$ and shifts emissions from E_0 to and E_{R0}. However, if the chosen measures do not reduce marginal abatement costs sufficiently (e.g., $MAC_M{}^1$), the combined reserve policy could still raise costs under certain market equilibrium compared to the program with the allowance reserve. Moreover, changes in marginal costs and total costs may differ. For example, in Figure 3, prices decline from P_M to $P_M{}^2$ with the introduction of the combined reserve policy with $MAC_M{}^2$. However, the implications for total costs are ambiguous: total costs with the allowance reserve (triangle *ABC*) could be greater than total costs without the reserve (triangle *ADE*) because of the increase in cap stringency.

Figure 3

Emission Control Market Equilibrium
With and Without a Combined Reserve Policy



While the analysis illustrates that cost containment through an allowance reserve can potentially raise costs, it is important to remember that the policy's net benefits depend on many factors. First, when raising costs, an allowance reserve will increase environmental benefits by lowering emissions. Consequently, net benefits may be positive. Second, an allowance reserve may reduce the variance of costs (and prices) by increasing cap stringency when abatements costs are low and decreasing cap stringency when costs. Third, an allowance reserve may lower costs under high cost market conditions, which may improve welfare if reducing cost impacts under the most severe conditions are disproportionate to potential increases under more less severe conditions.

In addition, in the context of regional GHG programs, such as the California cap-and-trade system, understanding the welfare consequences of these tradeoffs between costs and emissions is not straightforward because benefits are globally distributed, while costs are locally incurred. Thus, marginal costs may exceed local marginal benefits. Moreover, unilateral regional climate policy may be taken as a first step toward encouraging other regions and countries to adopt similar GHG commitments, so that full benefits may emerge only after multi-lateral agreements are reached. Given these factors, along with the complexities of estimating GHG reduction benefits generally, assessing the net benefits from alternative GHG cap-and-trade designs is not a simple task. Because of these complexities, this paper focuses only on evaluating alternative market outcomes in the context of the "cost containment" objectives often offered as the rationale for adopting allowance reserves, but does not attempt to evaluate net welfare consequences.

III. Analysis of California's AB 32 Cap-and-Trade System

The California Global Warming Solutions Act of 2006 (AB 32) mandates that California reduce its GHG emissions to 1990 levels by the year 2020. A key policy for achieving this target is a GHG cap-and-trade system, which caps emissions from large stationary sources starting in 2013 and then expands in 2015 to include liquid fuels (e.g., transportation and home heating fuels).[14] The program's rules have been developed over several rounds of rule-making by California's Air Resources Board (CARB), the agency responsible for achieving AB 32's targets. Under the current design, the system includes several design elements aimed at "cost containment", including: three-year compliance periods; allowance banking; use of CARB-certified emission offsets for compliance; and an allowance reserve. The system also has a price floor, implemented through a reserve price in GHG allowances auctions. The reserve prices start at \$10 per MMTCO_2e ("MMT") in 2012, rising annually at a rate of 5% plus inflation.

The allowance reserve will have 122 MMT of allowances that are re-allocated from the pool of allowances allotted for compliance (budgets) to the reserve.[15] Thus, the creation of the allowance reserve

[14] AB 32 does not mandate GHG emission targets after 2020. The policy was initially designed to cover the period 2012 to 2020, but was recently modified to cover the period 2013 to 2020 to allow further time for system design before implementation. The analysis in this paper is based on a cap-and-trade system implemented over the original policy period, 2012 to 2020.

[15] In the analysis, the reserve has 123.5 MMT of allowances. CARB provides limited discussion of why it chose to fill the reserve through increasing the cap's stringency. One of its "Cost Containment Principles" is that "Mechanisms must ensure the environmental integrity of the cap by not including a "safety valve"." CARB, "Cost Containment Options in a California Cap-and-Trade Program," presentation to a public meeting, June 22, 2010.

increases the stringency of the annual AB 32 emission targets. Specifically, the reserve will be filled with 1% of allowances from the first compliance period (2013-2014), 4% of allowances from the second compliance period (2015-2017), and 7% of allowances from the third compliance period (2018-2020). Table 1 shows the change in annual allowance budgets as a consequence of the establishment of the allowance reserve. Note that Table 1 reports information starting in 2012. While the cap-cap-trade program now will start in 2013, the analysis presented in this paper is based a program starting in 2012, which was the original start date for the program before the decision was made to delay the program by one year. This modeling decision does not affect the analyses' qualitative conclusions.

Table 1
AB 32 Cap-and-Trade Program: Emission Caps (Budgets), Reserves and Offset Use Limits

	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
GHG Emission Budget (MMTCO2e)	166	163	160	395	382	370	358	346	334	2,674
Quantity Allocated to the Reserve (%)	1%	1%	1%	4%	4%	4%	7%	7%	7%	
Reserve Allocation (MMTCO2e)	1.7	1.6	1.6	15.8	15.3	14.8	25.1	24.2	23.4	123.5
GHG Emission Budget less Reserve (MMTCO2e)	164	161	158	379	367	356	333	322	311	2,551
No Allowance Reserve (4% of budget)										
Offset Limit (MMTCO2e)	13	13	13	32	31	30	29	28	27	214
Offset Price at Use Limit ($/MTCO2e)	18	18	18	32	31	30	29	29	28	
With Allowance Reserve (8% of budget)										
Offset Limit (MMTCO2e)	7	7	6	16	15	15	14	14	13	107
Offset Price at Use Limit ($/MTCO2e)	13	13	13	20	19	19	19	18	18	

The reserve is split into three equally-sized tranches, each with a different trigger price. Trigger prices start at $40, $45 and $50 per $MTCO_2e$ ("MT") in 2012 for the three tranches and rise in subsequent years at an interest rate of 5% plus inflation. The program does not have a mechanism to replenish the reserve if it becomes depleted before 2020. Thus, the quantity of allowances initially placed in the reserve must be sufficient to provide cost/price mitigation sought by CARB over the entire eight-year program (2013 to 2020). In choosing the reserve's size, CARB has opted for a large quantity of allowances relative to anticipated emission reductions. While CARB anticipated 191 MMT of emission reductions would be necessary to meet allowances budget without the reserve (under its baseline scenarios), the reserve will increase the stringency of these budgets by 122 reductions $MMTCO_2e$. Thus, the reserve increases required reductions at these baseline emissions by 65%.[16]

[16] CARB based decisions about reserve size upon a scenario analysis of allowance prices under various programmatic assumptions. CARB, Proposed Regulation to Implement the California Cap-and-Trade Program, Staff Report: Initial Statement of Reasons (ISOR), Appendix G, Allowance Price Containment Reserve Analysis, October 28, 2010.

For the second part of the GHG reserve policy, CARB relaxed the offset use limit to compensate for the increased stringency in emission targets with the reserve.[17] When the reserve was established, CARB raised the limit on the portion of each compliance entities' allowance obligation that could be met with offsets from 4% to 8%.[18] Our analysis focuses on the economic and environmental consequences of the combined GHG reserve policy – that is, the creation of the allowance reserve and compensating adjustments to the offset use limits.

Based on the Rule's allowance budgets, CARB's modifications allow the use of up to 100 MMT of additional offsets over the 8-year compliance period. However, because the relaxation of offset limits (100 $MMTCO_2e$) is less than the allowances placed in the reserve (122 MMT), these changes increase the in-state reductions needed to meet the cap even if the additional flexibility in offset use is fully utilized.[19] Because of the discrepancy in these quantities, along with analyzing the modifications made by CARB, we also analyze a program in which the quantity of additional offsets that can be used exactly equals the quantity of allowances in the reserve.

Analysis of the AB 32 Cap-and-Trade Allowance Reserve

To analyze the implications of allowance reserve design for economic and environmental outcomes, market outcomes are evaluated based on estimates from CARB's updated economic analysis of the AB 32 cap-and-trade program.[20] This report provides market equilibrium outcomes that can be used to trace out multiple points along a carbon abatement cost curve.[21] CARB's analysis is based on an economic model of the energy sector but does not reflect some price responses, including reductions in economy-wide economic demand.[22] Relying on these cost estimates provides a means of assessing the

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[17] CARB, ISOR, 2010, pp. II-23 to II-24.

[18] This limit has the odd feature that the number of offsets that can be used for compliance declines as the cap becomes more stringent.

[19] The CARB staff report indicates that the quantity of allowances in the reserve and expanded quantity of offsets that can be used should be the same. CARB, ISOR, 2010, p. II-24.

[20] CARB, "Updated Economic Analysis of California's Climate Change Scoping Plan," Staff Report to the Air Resources Board, March 24, 2010. The MAC reflects market outcomes when complementary policies successfully achieve their emission reduction targets (CARB Cases 1 and 2).

[21] CARB (2010) reports cumulative emission reductions achieved under different allowance prices paths. CARB's analysis relies upon a forward-looking deterministic energy sector model in which abatement is costs reflect known technologies, energy demand, input prices, and baseline emissions. In all CARB cases, prices grow at the assumed 7% rate of interest.

[22] Consequently, the equilibrium prices reached by CARB in its two-stage analysis are somewhat lower than the first-stage results relied upon in this analysis. For example, two-stage general equilibrium allowance price estimates

impact of the reserve policy, and reflects CARB's assessment of the cost of emission reduction at the time when it designed its policy.

The analysis also incorporates the supply of allowances from the offset market and the allowance reserve. Offset supplies are based on the same offset supply curve used in CARB's updated economic analysis:

$$q_t = max\{0, (p_t - 8)/0.75\}$$

Reserves are released when market prices rise to reserve price triggers specified in the approved cap-and-trade rule (described above). Limits on offset use and the size of the allowance reserve are specified based on CARB's approved regulation. Given baseline emissions, the quantity of emission reductions needed to achieve compliance with CARB's cumulative emission reduction target is determined. Market equilibriums reflect abatement, offsets, and reserve allowances, when available, as well as the price floor. Figure 4 illustrates the resulting equilibrium prices with and without an allowance reserve at baseline emissions assumed in CARB's analysis.

There is significant uncertainty about many factors that potentially affect future allowance market equilibrium, including: baseline emissions, abatement costs, offset prices and supplies, allowance banking behavior (including the quantity of allowances banked at the end of the compliance period),[23] and the effectiveness of complementary AB 32 policies aimed at sources under the cap.[24] Our analysis estimates expected market outcomes given uncertainty in baseline emissions.[25] Uncertainty in other parameters is

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for CARB's Scoping Plan Policy Case are $21 per MT in 2020, whereas first-stage estimates for this case are $25 per $MTCO_2e$. These two-stage results fall somewhere between the Base Case and Low Cost Case results reported below.

[23] CARB's analysis assumes that allowance banks are fully exhausted by the program's end in 2020.

[24] CARB's AB 32 Scoping Plan includes many programs, in addition to the cap-and-trade system, aimed at sources under and outside the emissions cap. Compliance with complementary measures aimed at sources under the cap will reduce emission reductions that need to be achieved by the cap-and-trade system, thereby lowering costs. MAC curves assume that complementary GHG reduction policies successfully achieve emission reduction targets. However, there is uncertainty as to whether these complementary policies will achieve these targets. Failure to achieve these complementary policy goals has two effects on market outcomes. First, MAC abatement curves potentially shift downward as the cap-and-trade system has more opportunities for potential emission reductions at any given allowance prices. Second, failure to achieve complementary policy targets also increases the quantity of emission reductions that must be achieved through the cap-and-trade system. The net effect of these two outcomes will depend upon the shift in the MAC, although CARB's analysis indicates that failure to achieve complementary policy goals raises allowance prices. Thus, under these circumstances, allowances prices are likely to be higher than they otherwise would be.

[25] Our analysis differs from the analysis of Fell et al., who analyze allowance reserves within a stochastic dynamic framework.

evaluated through sensitivity analysis.[26] Market outcomes are evaluated assuming that baseline GHG emissions are normally distributed with a mean (μ) of 2,865 MMT over the period 2012 to 2020, which reflects baseline emissions in CARB's analysis, and a standard deviation of 50 MMTCO2e, calculated as: $\sigma = 0.83(E_h - E_l)$, where E_h and E_l are emissions under CARB high and low cases, respectively.[27] This implies there is a about a 68% probability that cumulative baseline emissions fall in the range: [2815, 2915 $MMTCO_2e$]. Competitive markets are assumed, so prices equal marginal costs.

Figure 4
California GHG Cap-and-Trade System:
Marginal Abatement Curves and Emission Caps with and without Allowance Reserve

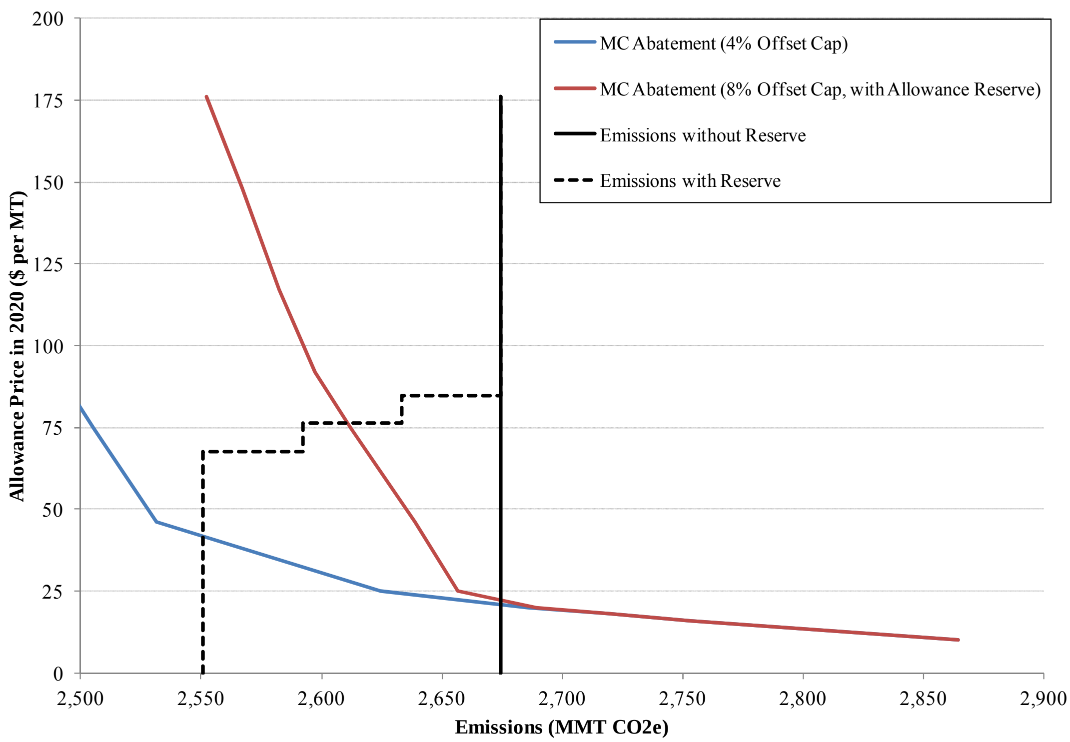


Figure 5 illustrates the assumed distribution of baseline GHG emissions, along with the corresponding allowance prices with and without the reserve at each level of baseline emissions.[28] Figure 5 illustrates the basic tradeoff offered by CARB's reserve policy. When baseline emissions are low and

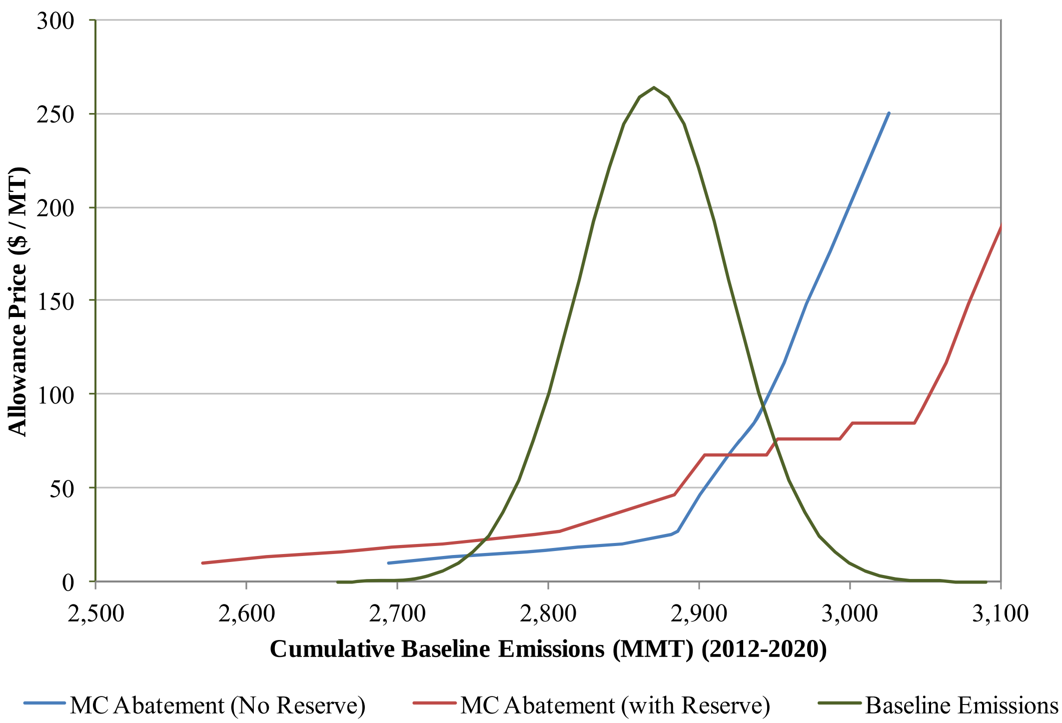
[26] Fell et al., 2010, evaluate uncertainty in baseline emissions and costs, including analysis of the implications of negative correlation between baseline emissions and offset costs.

[27] The CARB low price cases reflects CARB base case with offsets with the cap "loosened" by 45 MMTCO2e, resulting in a 2020 allowance price of $16 per MTCO2e. The CARB high price case reflects CARB base case without offsets with the cap "tightened" by 15 MMTCO2e, resulting in a 2020 allowance price of $176 per MTCO2e.

[28] In all analyses, prices are capped at $250 per MMT ($2020).

the cap is less stringent, the reserve policy raises allowance prices and lowers emissions. However, when baseline emissions are high, thus making the cap more stringent, the reserve policy lowers prices by expanding the net supply of compliance units (i.e., allowances plus offsets.) For each scenario, we examine the net effect of this tradeoff, by calculating expected values for prices, total costs, emissions and emission reductions. Prices in 2020 are reported and total costs reflect the present value of annual costs from 2012 to 2020. Total emissions reflect emissions from capped sources, while emission reductions reflect reductions from sources under the cap and outside the cap (i.e., offsets.)

Figure 5
California GHG Cap-and-Trade System:
Allowance Prices under Alternative Baseline Emissions
(With and Without Allowance Reserve)



Results

Table 2 reports expected market outcomes under CARB's proposed policy for base case assumptions. Expected prices are \$37 per MT in 2020 without the allowance reserve and \$45 per MT with the reserve. Consequently, CARB's reserve policy raises expected prices. Because the MAC curve is convex (as illustrated in Figure 5), expected prices are greater than CARB's point estimate at the expected level of baseline emissions (\$25 per $MTCO_2e$). Figure 6 illustrates the resulting cumulative distribution of prices with and without the reserve.

Table 2 also shows that expected total costs and emission reductions are larger with the CARB reserve policy in place: expected total costs are 89% higher with the allowance reserve (\$3.7 billion versus \$1.9 billion), expected emissions reductions (including offsets) are 61% greater (306 versus 190 $MMTCO_2e$) and expected emissions (from capped sources) are 4% lower (2,558 versus 2,674 $MMTCO_2e$). Under the base case distributional assumptions, the likelihood that the reserve is utilized is 22% and there is a small (less than 0.01%) chance that it is exhausted.

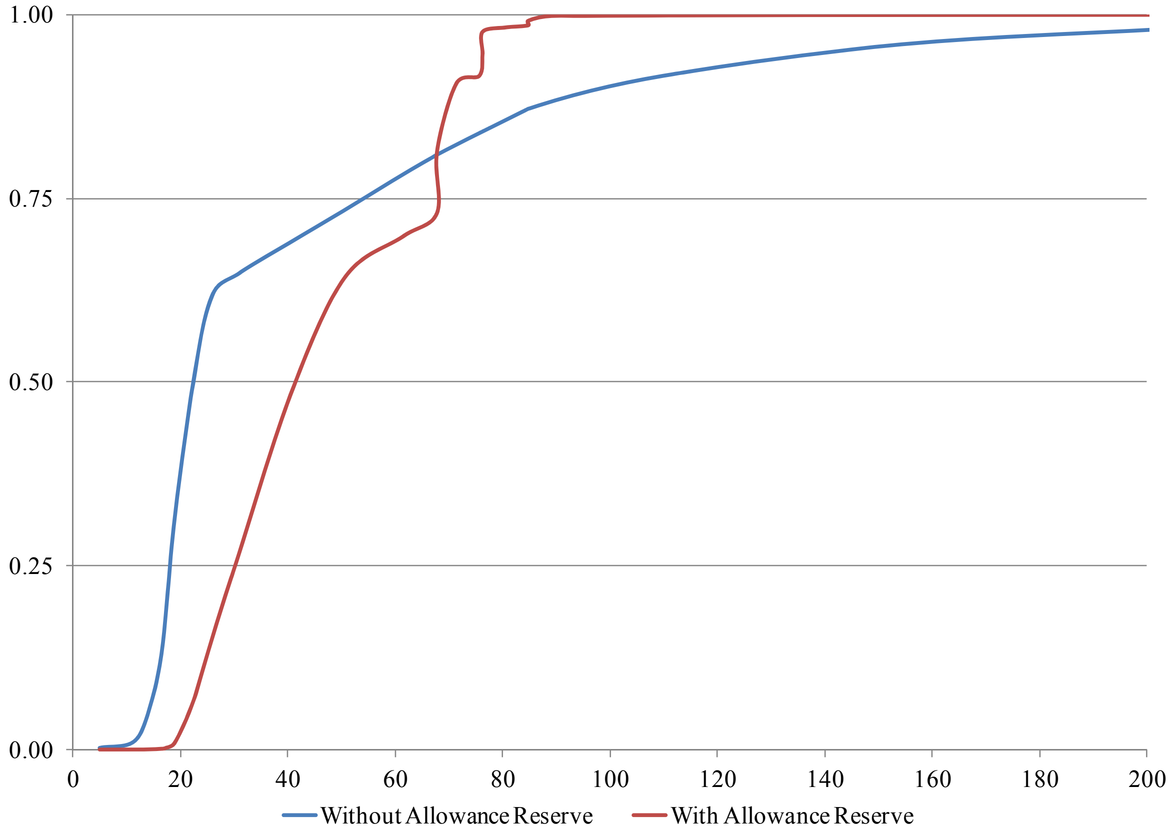
Expected prices are higher with the reserve policy for several reasons. First, as noted earlier, while CARB has increased offset use limits from 4% to 8%, the number of additional offset that can be used (107 $MMTCO_2e$) is less than the quantity of allowances taken from compliance budgets (124 $MMTCO_2e$).[29] Consequently, even if offsets were free, the allowance reserve increases the program's stringency. Second, although offset use limits have been relaxed, when prices are low, the market does not supply enough offsets (at the market price) to take full advantage of the added flexibility. With the reserve, the offset use limit does not bind until allowance prices are over \$40 per MT (under base case assumptions). By contrast, without the reserve, the limit is binding at prices of less than \$30 per $MTCO_2e$. Thus, when the reserve is in place and prices are below these levels, in-state sources must increase abatement to keep emissions below the cap, thus increasing marginal abatement costs.

[29] These totals reflect quantities over the 2012 to 2020 period used in the analysis.

Table 2
Analysis of Allowance Reserve:
Base Case and Alternative Baseline Emission and Costs Assumptions

	MC ($/MT)	Total Cost ($ Million)	Emissions (MMT)	Emission Reductions (MMT)	Likelihood of Reserve Use
Base Case					
No Reserve	37.0	1,947	2,674	190	
With Reserve	44.9	3,672	2,558	306	22%
Sensitivity Analysis					
Allowance Supply Cost					
Low Cost Abatement					
No Reserve	26.8	1,594	2,674	189	
With Reserve	40.4	3,433	2,553	312	7%
High Cost Abatement					
No Reserve	59.4	2,559	2,674	189	
With Reserve	53.4	3,738	2,569	294	46%
Low Cost Offsets					
No Reserve	35.6	1,659	2,674	189	
With Reserve	42.9	2,711	2,558	307	22%
High Cost Offsets					
No Reserve	45.2	2,546	2,674	190	
With Reserve	58.6	5,254	2,561	300	31%
Baseline Emission Distribution					
Shift Mean Emisisons (-60 MMT)					
No Reserve	19.8	1,033	2,674	130	
With Reserve	30.8	2,676	2,552	255	2%
Shift Mean Emisisons (-30 MMT)					
No Reserve	25.4	1,411	2,674	160	
With Reserve	37.0	3,172	2,553	282	9%
Shift Mean Emisisons (+30 MMT)					
No Reserve	57.6	2,772	2,674	220	
With Reserve	54.1	4,154	2,566	326	43%
Shift Mean Emisisons (+60 MMT)					
No Reserve	89.6	4,070	2,674	248	
With Reserve	63.4	4,588	2,581	342	67%
Variance ($\sigma = 1.5\sigma_0$)					
No Reserve	51.2	2,466	2,674	188	
With Reserve	46.7	3,645	2,564	300	30%
Variance ($\sigma = 2\sigma_0$)					
No Reserve	66.5	3,127	2,674	185	
With Reserve	49.1	3,653	2,571	293	35%

Figure 6
California GHG Cap-and-Trade System:
Distribution of Allowance Prices with and without Allowance Reserve



When considering the results in Table 2, it is important to remember that the reserve policy does not have a uniform impact regardless of economic conditions. Instead, the impact on prices and emissions varies with the underlying economic conditions. When emission reduction costs are low, the reserve policy makes the cap-and-trade program more stringent because the increase in cap-stringency outweighs the greater flexibility to use offsets. However, when costs are high, the policy makes the cap-and-trade program less stringent; on balance, costs are lowered by the expanded emission reduction opportunities. This shift in equilibrium outcomes has several important consequences. First, as discussed previously, if adjustments to cap stringency are negatively correlated with costs (i.e., the cap is relaxed (tightened) when costs are high (low)), the net benefits increase by reducing differences between marginal benefits and marginal costs. Second, as shown in Figure 6, CARB's reserve policy reduces the variance of price/cost outcomes. This may lower abatement costs by reducing the uncertainty of investment returns. Third, the estimates of expected prices and total costs in Table 2 reflect an aggregation across outcomes with equal weighting of alternative price and cost outcomes. However, the broader welfare consequences of high prices may be disproportionately large compared to outcomes when prices are low

– that is, there may be non-linear effects that suggest avoiding high allowances prices is particularly valuable. Such policy preferences may emerge due to non-linear general equilibrium effects, or risk aversion. While recognizing the potential for these non-linear effects, our analysis does not consider non-linear weightings of costs or benefits.

Uncertainty Regarding Baseline Emissions, Abatement Costs and Supply Costs

Base case results reflect uncertainty about baseline emissions. However, there is significant uncertainty about many of the parameters used in this analysis, including the distribution of baseline emissions and the underlying supply of GHG abatement and offsets. To examine these assumptions, market outcomes are estimated under alternative assumptions listed in Table 3, with results provided in Table 2.

Table 3
Sensitivity Analyses – Alternative Distribution and Cost Assumptions

Case	Description
Base Case	MAC and offset supply curves based on CARB (2010); offset limits and reserve triggers based on Proposed Regulation
Low Cost	MAC lower than Base Case (abatement 20% greater at any given price)
High Cost	MAC lower than Base Case (abatement 20% less at any given price)
Low Cost Offsets	Alternative offset supply curve: $q_t = (p_t - 4)/0.5$
Limited Offsets	Alternative offset supply curve: $q_t = p_t - 18$
Mean of Baseline Emissions	$\mu = \mu_0 + \Delta\mu\,,\ \Delta\mu\ \in\ \{\pm 30, \pm 60 MMTCO_2e\}$
Variance of Baseline Emissions	Standard deviation of baseline emissions: $\sigma = 0.75(E_h - E_l)$ and $\sigma = 1.0\ (E_h - E_l)$

As shown by Table 2, the sensitivity analyses results in a wide variation in market outcomes, with expected prices ranging from \$20 to \$89 per MT without the reserve policy, and \$31 to \$63 per MT with the reserve policy. The narrower range of prices with the reserve policy in place illustrates that the reserve policy reduces the variance of market outcomes by raising prices when costs are low and lowering prices when costs are high. Table 2 also shows that the reserve policy impact on expected prices depends on these baseline assumptions. In particular, the reserve policy lowers expected prices as abatement costs, baseline emissions, and the variance of baseline emissions are higher.

With higher abatement costs or baseline emissions, both of which effectively increase the stringency of the cap-and-trade policy, the reserve policy lowers expected allowance prices. The mechanism for this response is relatively simple: with higher allowance prices, the reserve is used more frequently and thus provides greater price mitigation, as measured by the difference in allowance prices with and without the reserve. Several scenarios illustrate this effect, including the High Cost MAC scenario and scenarios with higher Mean Baseline Emissions (+30 and +60 $MMTCO_2e$). In the base case, the reserve increases expected allowance prices by about \$8 per MT (\$44.9 – \$37.0 per $MTCO_2e$). However, with higher-cost market conditions, the reserve lowers expected prices by \$6 per MT (the High Cost scenario), \$4 per MT (mean baseline emissions + 30 $MMTCO_2e$), and \$27 per MT (mean baseline emissions + 60 $MMTCO_2e$).

The results also show that a reserve policy becomes more beneficial when there is greater uncertainty about factors that affect abatement costs. Because the reserve acts like a financial option, by releasing allowance when prices reach the trigger prices, its economic value increases when there is greater uncertainty about potential market outcomes. In this context, the price mitigation provided by the reserve policy increases as baseline emissions become more uncertain (i.e., higher standard deviation). As shown in Table 2, the reserve policy lowers prices by \$4 and \$17 per MT when the standard deviation of baseline emissions is increased 50% and 100%, respectively. The optionality offered by the reserve is also illustrated by the likelihood that some allowances will be drawn from the reserve. While there is a 22% likelihood that the reserve will be used under base case assumptions, this likelihood increases to 30% and 35% when the standard deviation of baseline emissions is increased by 50% and 100%, respectively. Similarly, the likelihood that the reserve is exhausted increases to 0.9% and 3.8% when the standard deviation of baseline emissions is increased by 50% and 100%, respectively.

Information on the likelihood that the reserve is exhausted can also inform decisions about the quantity of allowances to be placed in the reserve, particularly when there is no replenishment and the reserve is created by increasing the cap's stringency (i.e., reducing the quantity of allowances available for compliance.) Under these circumstances, the size of the reserve needs to reflect a balance of competing factors. If made too large, the reserve may unnecessarily increase costs (although reductions in benefits would be achieved.) If made too small, the reserve may become exhausted, and thus fail to fully mitigate costs under many circumstances. The analysis of CARB's reserve policy suggests that the likelihood that the reserve is exhausted is fairly low, even when adjusted for factors considered in the sensitivity analysis. In all but one sensitivity analysis reported in Table 2, the likelihood that the reserve is exhausted in less than 1%. In this one scenario, where the variance is twice the base case assumption (i.e., "Variance ($\sigma = 2\sigma_a$)"), the likelihood that the reserve is exhausted is less than 4%.

In contrast to the impact of increased abatement costs, increasing offset costs tends to reduce the price mitigation provided by the reserve policy. This effect occurs because CARB has increased reliance on the offset market through the compensatory increase in offset limits (from 4% to 8%) provided when increasing cap stringency (when filling the allowance reserve.) Because of these changes, a larger quantity of allowances is purchased when the reserve is in place, thus raising prices disproportionately when the reserve is in place. For example, higher-cost offsets increase prices regardless of whether the reserve is implemented, although the price increase is greater with the reserve in place (\$13 per $MTCO_2e$) than without (\$8 per $MTCO_2e$); as a result, the gap between expected prices with and without the reserve widens with higher offset costs. On balance, the reserve policy has increased the sensitivity of the cap-and-trade program costs to market conditions in the offset market.

In all sensitivities, expected totals costs and emission reductions are greater with the reserve, and expected emissions are lower. Expected total emissions decrease by 94 to 123 MT with the reserve in place across the sensitivities evaluated. Because implementation of the allowance reserve never actually relaxes program stringency, but only shifts the source of emission reductions, this result is not surprising. By contrast, the allowance reserve could, in principle, reduce expected total costs if abatement costs (or baseline emissions) were so high that the opportunity to use lower-cost offsets compensated for the increase in program stringency. Under base case cost assumptions, this only occurs when cumulative (2012-2020) baseline emissions rise to over 2,950 $MMTCO_2e$, which has a 4% likelihood of occurring under our base case assumptions. Across the alternative assumptions used in the scenarios, expected total costs are 13% to 160% greater with the reserve in place. Consequently, although the effect of California's allowance reserve on expected prices (and marginal costs) is sensitive to assumptions, the impact on total costs and emissions is directionally consistent across all scenarios.

Alternative Reserve Designs

The design of CARB's GHG reserve policy introduces particular tradeoffs between economic costs and environmental benefits given other market conditions. Certain modifications to this design could alter these tradeoffs, thus reaching different welfare outcomes. To better understand these design issues and the tradeoffs they introduce, several alternative policies, summarized in Table 4, are evaluated. Results are presented in Table 5.

Table 4

Sensitivity Analyses – Alternative Baseline Emission Distribution and Cost Assumptions

Case	Description
Reserves = Offsets	The quantity of allowances in the reserve equals the incremental increase in the offset use limit (4% of cap or 107 $MMTCO_2e$)
50% of Reserves from Cap	Reserve is 123.5 MMT with 50% of allowances from the cap (emission budgets); offset use limits is set at 6%
0% of Reserves from Cap	Reserve is 123.5 MMT with 0% from allowances from the cap (emission budgets) ; offset use limits is set at 4%
Replenishment	Reserve is initially filled with 41 MMT from the baseline, and the subsequently replenished through offset purchases

One alternative is a policy in which the reduction in compliance budgets from creating the reserve equals the increase in the limit on offset use. Specifically, a policy is analyzed in which the quantity of allowances in the reserve (and the reduction in allowance budgets) is 107 MMT (rather than 123.5 $MMTCO_2e$), which equals the increase in the offset use limit in CARB's reserve policy (see "Reserves = Offsets" in Tables 5 and 6.) This reduction in reserve size lowers expected prices from \$45 to \$40 per $MTCO_2e$, but the expected price when the reserve is in place still exceeds the expected price absent the reserve (\$37 per $MTCO_2e$.) Despite the smaller reserve, the likelihood that the reserve is exhausted is still less than 0.1%.

Table 5
Analysis of Allowance Reserve:
Base Case and Alternative Baseline Emission and Allowance Supply Costs

	MC (\$/MT)	Total Cost (\$ Million)	Emissions (MMT)	Emission Reductions (MMT)	Likelihood of Reserve Use
Base Case					
No Reserve	36.9	1,947	2,674	190	
With Reserve	44.9	3,672	2,558	306	22%
Alternative Reserve Designs					
Reserves = Offsets	40.4	3,401	2,571	293	14%
50% of Reserves from Baseline	38.5	2,601	2,618	246	18%
0% of Reserves from Baseline	32.1	1,745	2,678	187	14%
With Replenishment	36.0	2,425	2,636	230	16%

Another policy alternative would allow a portion of the GHG reserve to be filled with "free" allowances – that is, without reductions in the allowance budgets used for compliance. By allowing some free allowances, this alternative introduces a tradeoff between environmental criteria: while emissions may exceed predetermined caps (under certain market conditions), the policy may still improve environmental outcomes when measured by *expected* emissions. Two scenarios are examined in which either 50% or 0% of the reserve is filled with allowances from under the cap. As the portion of the reserve taken from emission budgets declines, expected prices, total costs and emission reductions all decline, and expected emissions increase. Expected prices with the reserve policy fall from $45 per MT in the base case to $38 and $32 per MT with 50% and 0% of the reserve filled from the cap, respectively. With 50% of the reserve filled from the cap, expected total costs decline by 29% (from $3.7 billion to $2.6 billion). With 0% of the reserve filled from the cap, expected total costs are $1.7 billion, or 10% below prices without the reserve.

While these alternatives lower costs, they also increase emissions relative to a reserve filled completely with allowances from the cap. When 50% of the reserve allowances are taken from compliance budgets, expected total emissions are 60 MMT higher than CARB's reserve policy, but are still 57 MMT below the AB 32 cumulative target (as specified by CARB). Under base case assumptions, there is less than a 1% likelihood that this occurs; under the most conservative assumptions (i.e., Variance ($\sigma = 2\sigma_a$)), there is a 12% likelihood that this occurs. Despite introducing the potential for emissions to exceed the AB 32 cumulative target, this happens infrequently; while compliance budgets are reduced by 50% to fill the reserve, aggregate emissions will increase only when more than 50% of the reserve is used.

When the cap is not adjusted at all ("0% of Reserves from Baseline"), expected emissions are 4 MMT greater than the cumulative target, comparable to a 0.2% increase in expected emissions.[30] There is a 14% likelihood that the reserve will be utilized (under base case assumptions), which would result in increased emissions (compared to the program without the reserve.) Thus, while emissions will exceed the pre-determined target when the reserve is used, the increase in expected emissions is relatively small. However, this conclusion is sensitive to baseline assumptions. As shown in Table 6, which reports results of sensitivity analyses for the "0% of Reserves from Baseline" policy, these impacts vary widely in terms of cost and environmental impacts.

Analysis of these scenarios illustrates that the choice of policy criteria for measuring environmental performance has consequences for program design, and thereby for policy outcomes. CARB's reserve policy reflects the decision to use a strict measure of environmental performance, in

[30] The difference in expected emission reductions (with and without the reserve) may differ from the difference in emissions since emission reductions are measured relative to a varying baseline.

which emissions are *never* permitted to exceed established targets, but can fall below these targets. As a consequence of this choice, the reserve policy improves environmental performance when measured by *expected* emissions. While potentially welfare enhancing, this improvement in environmental outcomes seems to be an unintended outcome of a policy aimed at "cost containment". However, relying on a different set of environmental and cost criteria could lead to policies with preferred balances between environmental and cost outcomes.

Table 6
Analysis of Allowance Reserve:
Scenario: 0% of Reserves from Cap
Base Case and Alternative Baseline Emission and Costs Assumptions

	MC ($/MT)	Total Cost ($ Million)	Emissions (MMT)	Emission Reductions (MMT)	Likelihood of Reserve Use
Base Case					
No Reserve	36.9	1,947	2,674	190	
With Reserve	44.9	3,672	2,558	306	54%
Sensitivity Analysis					
Baseline Emission Distribution					
Shift Mean Emisisons (-60 MMT)					
No Reserve	19.1	1,034	2,674	130	
With Reserve	18.8	1,024	2,675	130	1%
Shift Mean Emisisons (-30 MMT)					
No Reserve	25.1	1,409	2,674	160	
With Reserve	23.9	1,358	2,676	159	5%
Shift Mean Emisisons (+30 MMT)					
No Reserve	57.6	2,771	2,674	219	
With Reserve	43.3	2,158	2,684	211	31%
Shift Mean Emisisons (+60 MMT)					
No Reserve	89.6	4,070	2,674	248	
With Reserve	55.4	2,554	2,696	229	54%
Variance ($\sigma = 1.5\sigma_0$)					
No Reserve	50.8	2,465	2,674	188	
With Reserve	35.9	1,789	2,684	182	23%
Variance ($\sigma = 2\sigma_0$)					
No Reserve	66.0	3,127	2,674	185	
With Reserve	39.9	1,891	2,690	180	29%

A final policy alternative allows the reserve to become replenished as it becomes depleted. This policy potentially mitigates some of these tradeoffs between cost and emissions confronted by policies, such as CARB's program, which fills the reserve only once at the outset of the program for the entire 2012 to 2020 period. As discussed above, this approach creates a challenge for policymakers given uncertainty about future costs, and tradeoffs between a reserve that is too large, thus unnecessarily raising costs, and one that is too small, thus providing too little price mitigation. To assess the potential for reserve replenishment, an alternative reserve design is designed in which: (1) one-third (41 MMTCO_2e) of the reserve is initially filled from the cap; (2) the remaining two-thirds of the reserve is filled with allowances through offsets purchases, if needed; and (3) the offset use limit is raised by 41 MMTCO_2e. This approach provides the same level of price mitigation and maintains strict environmental integrity (since emissions will not exceed the cumulative CARB target), but accomplishes these goals with a smaller initial increase in cap stringency. With replenishment, expected prices with the reserve policy decline from $45 to $37 per MT$CO_2$e, which is about equal to expected prices without the reserve. Replenishment also reduces total costs by 34%, while expected emissions are still 38 MMTCO_2e, lower than the CARB cumulative target. Thus, an allowance incorporating greater flexibility to adjust its size to economic need offers an opportunity to lower costs while meeting environmental criteria.

Conclusion

Cost containment has become an increasingly important element of cap-and-trade design. However, measures aimed at cost containment potentially draw upon increasingly complex approaches in an effort to balance environmental and cost outcomes. In these cases, careful assessment of these cost and environmental outcomes becomes increasingly important, since economic and environmental outcomes may depend on particular design details. As our analysis of California's allowance reserve illustrated, failure to perform such careful assessments could lead to unintended outcomes.

Bibliography

California Air Resources Board (CARB), Proposed Regulation to Implement the California Cap-and-Trade Program, Staff Report: Initial Statement of Reasons (ISOR), Appendix G, Allowance Price Containment Reserve Analysis, October 28, 2010.

CARB, *Updated Economic Analysis of California's Climate Change Scoping Plan*, Staff Report to the Air Resources Board, March 24, 2010.

Fell, Harrison, Dallas Burtraw, Richard Morgenstern, Karen Palmer, and Louis Preonas, "Soft and Hard Price Collars in a Cap-and-Trade System, A Comparative Analysis", Resources for the Future, Discussion Paper 10-27, April 2010.

Grull, Georg and Luca Taschini, "Cap-and-Trade Properties under Different Scheme Designs," MIT Center for Energy and Environmental Policy Research, Working Paper 09-019, November 2009.

Maniloff, Peter and Brian Murray, "Allowance Price Containment Options for Cap-and-Trade Legislation," Nicholas Institute Discussion memo on H.R. 2454, American Clean Energy Security Act, October 5, 2009.

Murray, B.C, R.G. Newell, and W.A. Pizer, 2009, "Balancing Cost and Emissions Certainty: An Allowance Reserve for Cap-and-Trade," *Review of Environmental Economics and Policy* 3(1): 84-103.

Newell, Richard, William Pizer and Jiangfeng Zhang, 2005, "Managing Permit Markets to Stabilize Prices," *Environmental & Resources Economics* 31:133-157.

Stocking, Andrew, "Unintended Consequences of Price Controls: An Application to Allowance Markets", Congressional Budget Office, Working Paper 2010-06, September 2010.

Unold, Wolfram, and Till Requate, "Pollution Control by Options Trading," *Economics* Letters 73: 353-358, 2001.