California's Cap-and-Trade Market Through 2030: A Preliminary Supply/Demand Analysis

By Severin Borenstein, James Bushnell, and Frank Wolak*

* This research was supported by a grant from the Energy Foundation. The authors were members of the Emissions Market Assessment Committee and Market Simulation Group that advised the California Air Resources Board (ARB) in 2012-2014. The opinions in this paper do not necessarily represent those of the ARB or any of its employees. Email addresses: Borenstein: severinborenstein@berkeley.edu; Bushnell: jbbushnell@ucdavis.edu; Wolak: wolak@stanford.edu.

SUMMARY

California's cap and trade market is perhaps the most important contribution the state has made to global understanding of the institutions that will help reduce greenhouse gas emissions and climate change. State policymakers are currently discussing the terms for extending the market to 2030. In this paper, we attempt to inform that policy process by estimating the distribution of potential outcomes of the cap and trade market under alternative assumptions about the market rules and the additional state policies for reducing greenhouse gases.

We extend our earlier analysis of the 2013-2020 cap-and-trade program (Borenstein, Bushnell, Wolak and Zaragoza-Watkins (2016)) to analyze the supply-demand balance in California's cap-and-trade market for greenhouse gasses (GHGs) through 2030. We estimate the distribution of business-as-usual (BAU) emissions and then consider the impact of different sources of GHG abatement, including both abatement that is responsive to the price of emissions allowances and the state's other GHG reduction programs. As we showed in our earlier work, there is significant uncertainty in the BAU emissions levels due to uncertainty in economic growth and other factors. Our analysis also illustrates how most of the planned abatement will not be sensitive to the price of allowances, although there is a large amount of uncertainty about the aggregate impact of these abatement sources. The combination of uncertainty in BAU emissions and in the supply of abatement implies a high probability that the equilibrium price of allowances evolves either to the price floor or to a price ceiling at which additional allowances would be released.

In our base case in which safety valve allowances from the Allowance Price Containment Reserve (APCR) are available only at a ceiling price $60 above the floor price and a hard price ceiling is enforced at that level, we find that there is a 34% probability of the price hitting this ceiling, a 47% probability of the price settling at the floor, and a 19% probability of a price between the floor and the ceiling. The distribution implies a probability-weighted expected price in 2030 of $51.62 (in 2015 real dollars).[1] We also analyze the potential price distribution if the allowances in the APCR are made available at intermediate price steps ("speed bumps") between the floor and ceiling. In this analysis, the probability of reaching the price ceiling is reduced to 16%. We also examine a scenario in which the price ceiling is lowered from $60 above the floor to $40 above the floor, and perform sensitivities in which the supply of abatement through complementary policies is increased or reduced.

[1] This calculation depends on the adoption of a hard price ceiling. Without a hard price ceiling, the expected price would be significantly higher.

I. INTRODUCTION

In previous work, Borenstein, Bushnell, Wolak, and Zaragoza-Watkins (2016), henceforth BBWZ, analyzed the distribution of possible equilibrium prices and quantities in California's cap and trade market as it was originally established for 2013-2020 under Assembly Bill 32 (2006). In this paper, we extend that analysis to examine the possible distribution of equilibrium prices and quantities for extension of the program through 2030 under assumptions that correspond to proposals currently under discussion among California policymakers. These discussions are ongoing, so the assumptions made here may not reflect the most recent proposals, but we have attempted to follow the basic outline of current proposals in order to provide guidance as to the distribution of outcomes that might result.

We follow BBWZ in the basic organization of the analysis: first, we estimate a seven-variable cointegrated vector autoregression (VAR) for the 1990-2012 time period. We use the parameters from that estimation – along with actual variable values through 2015 – to estimate the distribution of possible greenhouse gas (GHG) emissions through 2030 under "business as usual" (BAU). BAU represents the distribution of possible GHG outcomes if environmental policies continued on the pre-existing trajectory, without significant deviations from that trend in emissions regulations and without GHG pricing. Second, we adjust the distribution of BAU outcomes for the major California policies aimed at reducing GHG emissions apart from the cap and trade allowance price, including renewables portfolio standard for electricity generation, the low carbon fuel standard and automotive fuel economy standards. We also consider the possible GHG content of electricity imports, the effect of linkage of California's cap and trade program with Québec, and possibly Ontario, the use of offsets, and the effect of electricity price increases unrelated to the cap and trade program. Third, we incorporate the potential effects of a price on GHG emissions as it is passed along to consumers, and the resulting decline in consumption of fossil fuels. The result of this analysis is a probability distribution of possible prices in the cap and trade market in 2030.

As in BBWZ, we do not explicitly forecast the price path between current levels and 2030. Rather, we assume that market participants will be able to bank sufficient allowances into the future and/or borrow sufficient allowances from the future, in order to equalize the current price at any point in time with the (appropriately discounted) expected price in 2030.[2] Section II-A of BBWZ discusses in greater detail the implications for price paths over the course of the

[2]We also do not attempt to consider possibilities for extension of the program beyond 2030. Implicitly, we are assuming that the supply of allowances in a program through 2030 would be fully available for 2030 and earlier, and of no value beyond 2030.

program.

Of course, any forecast of this type requires many assumptions and modeling choices. Our modeling closely follows BBWZ, and we describe in detail where we have departed from that previous work. We believe we have adopted reasonable values for the relevant parameters in the modeling, but we attempt to be as transparent as possible about all of our assumptions, and we evaluate a variety of alternative values. In the next section, we give an overview of the estimation method, for which more detail is available in the appendix. Section III presents the results on emissions and allowance prices. We conclude in section IV.

II. ESTIMATION OF BAU EMISSIONS AND ABATEMENT

Our modeling of BAU emissions follows the estimation in BBWZ using data for 1990-2012. The vector autoregression variables are: California in-state electricity production net of hydroelectricity, total vehicle miles traveled (VMT), natural gas emissions (other than from electricity generation) and other industrial GHG emissions, real retail gasoline price, real gross state product, GHG emissions intensity of in-state thermal electricity generation, and GHG emissions intensity of VMT.[3] Whereas BBWZ used the parameter estimates from the vector autoregression and data through 2012 to forecast a distribution of possible values for 2013-2020, here we use the parameter estimates from the vector autoregression and data through 2015, the last year for which data are available, to estimate a distribution of possible values for 2016-2030.

The forecasted values of the in-state electricity production (net of hydro) are adjusted for zero-carbon electricity generation, as explained in the appendix, and then multiplied by the forecasted emissions intensity of thermal generation to derive an estimate of GHG emissions from fossil fuel combustion in electricity generation. Similarly, forecasted VMT are multiplied by the forecast of emissions intensity of transportation to derive a BAU forecast of transportation emissions. Finally, industrial/natural gas emissions are added to create the estimated distribution of total in-state BAU GHG emissions. The actual and estimated distribution of annual broad scope emissions are illustrated in figure 1. The solid line depicts actual emissions through 2015 and the mean of estimated annual emissions from 2016 onward. The stair-step line illustrates the annual cap of emissions levels as proposed by the California Air Resources Board (ARB).

If, as we assume in this analysis, emissions allowances are bankable to future years, the most relevant comparison of emissions to a cap is the distribution of cumulative emissions through 2030 compared to the aggregate cap over the same period. The forecast distribution of cumulative BAU emissions from 2013 to 2030

[3]See BBWZ for detailed description of these variables.

is presented in figure 2, where the solid line is the mean forecast and the dashed lines are the 5% and 95% confidence bounds.[4] The vertical series of dots in each year display the outcome BAU emissions from the 1000 draws from the estimated distribution of cumulative emissions, which we discuss below. The dashed line illustrates our assumption of the cumulative cap over the 2013-2030 time periods, of 5115 million metric tonnes (MMtons).[5]

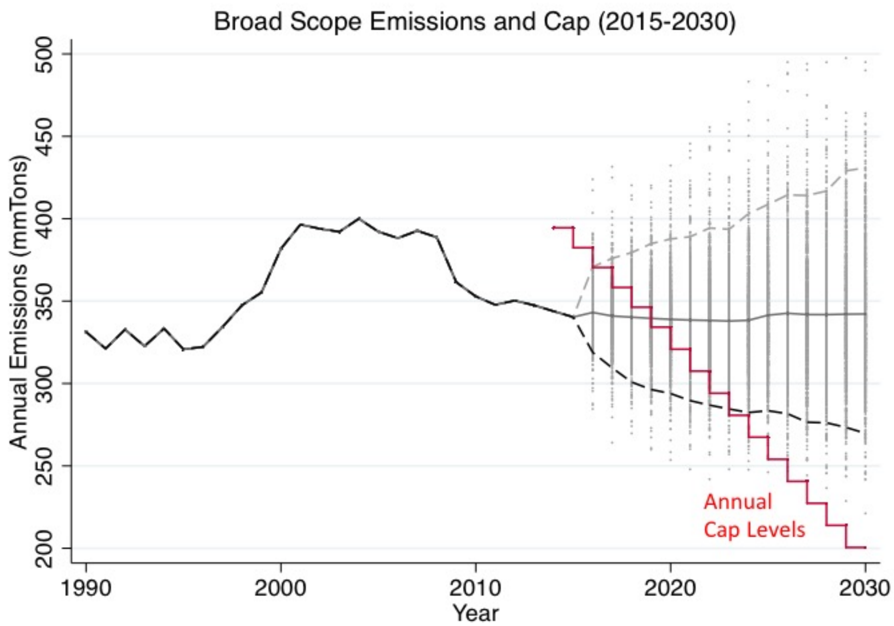

Figure 1. Estimated Distribution of Business-as-Usual Annual Emissions

It is important to recognize that the estimates of future BAU emissions from this procedure incorporates trends in the underlying variables such as the emissions intensities of electricity generation and vehicle miles traveled. Thus, the BAU estimates effectively assume that the trends in the seven VAR variables are likely to continue. Adjustments to the BAU estimates are appropriate to the extent that new or changed policies suggest a deviation from the trend through 2015.

[4]The data used for the VAR estimates are summarized in table A1 in the Appendix. The annual estimated distributions of VAR variables for 2016-2030 are summarized in table A3.

[5]We combine the 2013-2020 cap of 2509 mmTons with the ARB's proposed trajectory for the cap for 2021-2030 which totals to 2606 MMtons. Our analysis therefore assumes that any unused allowances from the 2013-2020 period will be available for compliance in later periods. We make varying assumptions about the APCR, as described below.

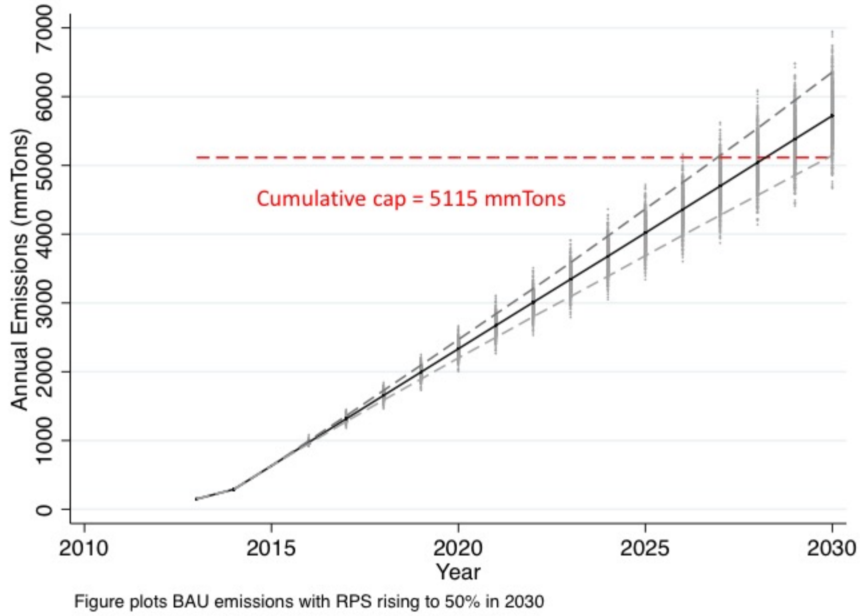

Figure 2. Estimated Distribution of Business-as-Usual Cumulative Emissions

After establishing these BAU estimates, we next consider possible adjustments in a number of areas that are completely or mostly unresponsive to the cap and trade allowance price: fuel economy and other mobile source abatement policies, CO_2 content of electricity imports, offsets, allowance trade with Canadian provinces, and electricity demand response to price increases apart from cap and trade.

We then incorporate possible impacts of abatement that are responsive to the cap and trade price. Drawing on BBWZ, we use elasticity estimates from the existing literature to evaluate the potential reduction in emissions from transportation fuels, natural gas, and electricity generation.

The magnitudes of the abatement achieved under our assumptions from the various sources are summarized in table 1. More details of the adjustments we make for non-price-responsive and price-responsive abatement are presented in the appendix.

As in BBWZ, we incorporate both estimation error and forecast error in evaluating the level of uncertainty about BAU emissions by resampling 1000 times

Table 1—Summary of Abatement Supply

	Abatement over 15 Years				Annual
	Mean	S.D.	5%	95%	Average
Electricity					
Price Response (floor)	10.3	1.5	7.8	12.8	0.7
Price Response (ceiling)	30.0	4.4	22.8	37.2	2.0
Transport					
Price Response (floor)	21.6	3.2	16.4	26.8	1.4
Price Response (ceiling)	66.5	9.7	50.6	82.3	4.4
Natural Gas					
Price Response (floor)	46.3	4.0	39.7	52.9	3.1
Price Response (ceiling)	121.2	10.1	104.8	137.7	8.1
Exogenous Elec.					
rate effects	78.0	11.2	59.8	96.2	5.2
Advanced Clean Cars	227.9	156.0	22.8	483.5	15.2
Mobile Source Strat.	69.4	10.3	52.5	86.3	4.6
Elec. Imports	218.7	35.9	160.0	277.1	14.6
Offsets	198.4	48.5	119.7	277.5	13.2
Net Canada Trade	-100.1	67.0	-209.4	9.3	-6.7
Total at Price Ceiling	909.9				60.7
Total at Price Floor	770.4				51.4

Notes: Ceiling price is assumed to rise at 5% prior to 2020.
After 2020 Ceiling price is set \$60 above the floor price.
Prices are assumed to be at the floor in 2016-17.

from the distribution of residuals from the VAR, re-estimating the VAR with each generated sample, and creating estimated distributions out to 2030 based on the resulting variable values and parameters from each sample. For each draw, we also create independent random draws of each of the possible adjustments to the BAU emissions estimates, as described in BBWZ, with the exception of zero-carbon in-state electricity generation, which is incorporated into the BAU calculations as explained below. The random draws of each adjustment are based on a low and high case that form the support of a symmetric $\beta(2,2)$ distribution, just as in BBWZ. The abatement quantities described in table 1 reflect this random distribution, with the second column of table 1 summarizing the mean value of abatement across 100,000 draws of abatement quantities for each policy or measure.

Our mean estimate of the cumulative 2013-2030 distribution of BAU emissions is 5739 MMtons. The implications of this estimated distribution can be assessed by comparing these quantities to our abatement assumptions in table 1. Under the assumption that allowance prices in 2030 reach the allowance price ceiling assumed in our base case, the mean amount of total abatement is 910 MMtons. Under the assumption that allowance prices reach the floor in 2030, the mean abatement amount is 771 MMtons. As described in the following section, the cap for this period, excluding the APCR, is 4941, implying that just under 800 MMtons of abatement are necessary to comply with the cap under the mean forecast of BAU. Note that abatement at the floor price is close to, but not quite at 800 MMtons.

III. ESTIMATES OF POSSIBLE OUTCOMES FROM EXTENDING CAP AND TRADE TO 2030

Following BBWZ, we create a demand for abatement based on the difference between BAU emissions and the emissions cap, and a supply of abatement that includes price-responsive abatement and other adjustments that change emissions. The supply function includes abatement from the sources discussed in the previous section (and appendix), except for the zero-carbon in-state electricity generation, which is incorporated in the BAU.

The sources that are not price-responsive are assumed to be available at the price floor, as discussed in BBWZ. Above the price floor, additional supply is available from price-responsive abatement – a small quantity of which is available even at the price floor, because even the floor price would incentivize some emissions reductions – and from additional allowances made available from the Allowance Price Containment Reserve (APCR).

Our calculation is illustrated in figure 3, in which a hypothetical supply of abatement is represented by the upward sloping black line. This abatement supply curve is flat at both the allowance floor and ceiling prices, representing the assumption of a hard price ceiling and floor, which implies that allowances would be added to the market if price rises above the ceiling or would be withdrawn from the market if price falls below the floor. The demand for abatement is equal to the distance between BAU emissions and the emissions cap. There is a probability distribution of the abatement demand based upon the underlying distribution of BAU emissions. Thus figure 3 illustrates several possible demand curves. The resulting allowance price would be where the abatement supply curve and the demand for abatement intersect.

We analyze a number of different policies, but we begin by studying a "base case" with a hard price floor and ceiling, and with all allowances in the APCR available at the ceiling price.[6] In the base case, the price floor and ceiling each rise at 5% annually (in real dollars) until 2020. After 2020, the price floor continues

[6] In its most straightforward implementation, a hard floor means that the government stands ready

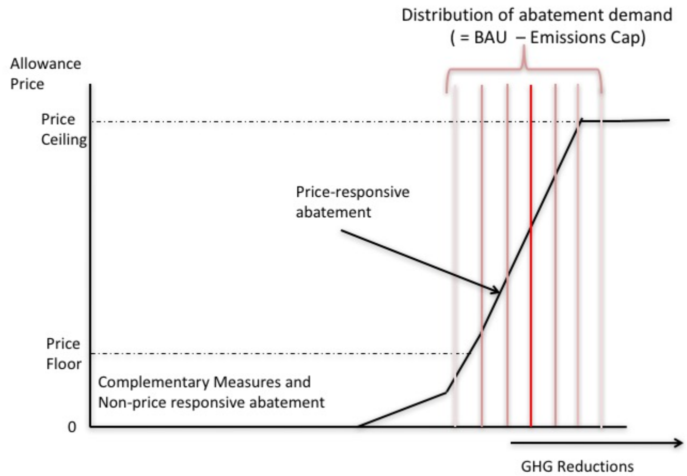

Figure 3. Hypothetical Supply and Demand for Abatement

to rise at 5% and the price ceiling is set at $60 above the price floor in each year. All APCR allowances from the current program are assumed to be available to be carried over beyond 2020, and the full quantity of allowances in the APCR, 174 MMtons, is assumed to be made available at the price ceiling. In addition, and critically, all of our analyses assume that a hard price ceiling is enforced.[7] Without a hard price ceiling the significant probability we find of exhausting the APCR would be associated with prices much higher than the ceiling, which may be viewed as politically unacceptable, and which would substantially increase expected prices in earlier years.

The resulting abatement supply curve is shown in figure 4. Our analysis yields probabilities of the 2030 equilibrium price in the market being at the floor, on the upward sloping portion of the abatement supply function, or at the ceiling. Within the outcomes at the ceiling, we can separate the probability that only allowances from the APCR will be used versus the cases in which the APCR is exhausted and additional allowances are sold at the hard price ceiling. These probabilities imply a probability-weighted expected price of $51.62 in 2030.[8] These probabilities are

to restrict sales or buy back allowances at the floor price, and a hard ceiling means that the government stands ready to create and sell additional permits at the ceiling price. In practice, there are many ways supply could be adjusted to enforce the floor and ceiling.

[7]The funds from these additional purchases could be used to reduce GHG emissions through other programs in California or elsewhere, but we do not make any assumption about the use of these funds.

[8]The $51.62 is in 2015 dollars. That is, it is adjusted for inflation back to 2015, but it is not adjusted for any rate of return above inflation. It is impossible to know what rate of return investors would

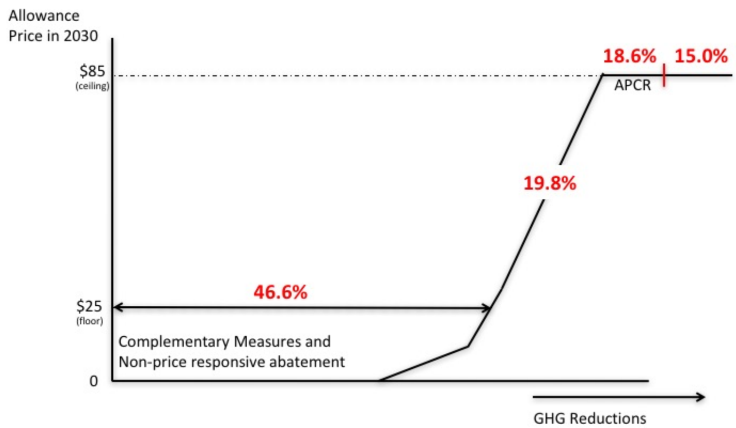

Figure 4. Distribution of outcome probabilities with hard price ceiling, no steps

also reported in table 2.

To reach these probabilities, we have had to make many assumptions, as documented in the appendix. Observers may disagree with some of the assumptions we have made, and may want to know how specific changes could change the resulting probabilities. To accommodate such inquiry, we also report in table 3 the effect of adding 100 MMtons of additional abatement in aggregate through 2030 on the probabilities of the equilibrium price evolving to the floor, the upward supply slope, in-APCR, and beyond APCR, and the probability-weighted expected price in 2030. Likewise, we report the effect of reducing abatement by 100 MMtons in aggregate through 2030.

A second scenario that we examine is identical to the base case, except the allowances in the APCR are made available in equal quantities at two lower price points: 87 MMtons at $20 above the price floor and 87 MMtons at $40 above the price floor. This creates flat step sections in the abatement supply curve, which have become known as "speed bumps" in California policy discussions, as pictured in figure 5. Moving the APCR allowances from the ceiling price to intermediate prices of course lowers the probability of hitting the ceiling price

demand to purchase allowances in advance, but discounting back to 2018 at a 5% rate would imply a price in 2018 of $28.74. To the extent that legal or legislative uncertainty remains in 2018, it is likely that market participants would require a higher expected rate of return in order to purchase and hold allowances for future use. This would result in a lower expected price in 2018.

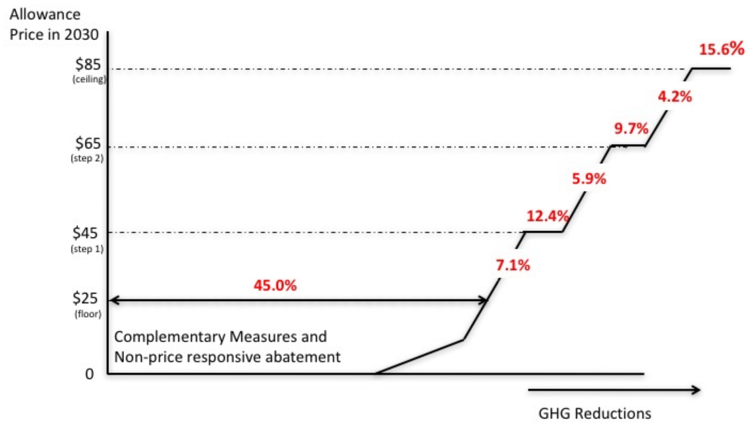

Figure 5. Distribution of outcome probabilities, hard price ceiling and steps

and lowers the overall expected price. It also slightly lowers the probability of being at the floor price and slightly raises the probability of exceeding the capped emissions quantity, because the lower expected price yields less price-responsive abatement over the years of the program. The probabilities of being on each segment of the resulting abatement supply curve are shown in figure 5 and are reported in table 2. The probability-weighted expected price in 2030 would then be $45.53.[9]

Finally, we consider a third scenario that is similar to the first and second, but with a lower price ceiling: $40 above the price floor after 2020 rather than $60 about the price floor. We examine both the case with all of the APCR allowances available at the price ceiling and with dividing them into two steps. The intermediate steps at which the APCR allowances are released are then $13.33 above the price floor and $26.67 above the price floor. The probabilities of being on each segment of the resulting abatement supply curves are reported in table 2. The probability-weighted expected price in 2030 would then be $44.47 with all APCR allowances at the price ceiling and $40.07 if the APCR allowances are made available at intermediate steps.[10]

[9]Discounting back to 2018 at a 5% real interest rate implies a price of $25.35 in 2018.
[10]Discounting back to 2018 at a 5% real interest rate implies in 2018 a price of $24.76 if all APCR allowances are at the price ceiling and $22.31 if they are released at intermediate steps.

Table 2—Allowance Price Probabilities

Scenario	Probability of 2030 price at Allowance Price Level								Probability-weighted price in 2030
	at floor price	below 1/3 C price	Step 1 1/3 C price	above 1/3 C below 2/3 C	Step 2 2/3 C price	above 2/3 C below C	In APCR at C price	Beyond APCR at C price	
$85 2030 Ceiling no steps	46.2 %	7.2 %	NA	6.4 %	NA	6.3 %	18.7 %	15.2 %	$ 51.62
$85 2030 Ceiling 2 steps	45.0 %	7.2 %	12.4 %	5.8 %	9.7 %	4.1 %	NA	15.9 %	$ 45.53
$65 2030 Ceiling no steps	45.0 %	4.8 %	NA	4.6 %	NA	5.1 %	21.2 %	19.3 %	$ 44.47
$65 2030 Ceiling 2 steps	44.0 %	4.9 %	12.6 %	4.4 %	10.8 %	3.5 %	NA	19.8 %	$ 40.07

Notes: Ceiling price (C price) is assumed to rise at 5% prior to 2020. After 2020 it is set $60 or $40 above the ARP (floor price).
APCR is 174 mmTons in scenarios with no steps. In steps scenarios, the APCR is distributed evenly between the two steps (87 mmTon per step).

Table 3—Sensitivity to Impact of Complementary Policies

Scenario	Probability of 2030 price at Allowance Price Level						Probability-weighted price in 2030
	at floor price	below 1/3 C price	above 1/3 C below 2/3 C	above 2/3 C below C	In APCR at C price	Beyond APCR at C price	
$85 2030 Ceiling base case	46.2 %	7.2 %	6.4 %	6.3 %	18.7 %	15.2 %	$ 51.62
100 mmTons more Abatement	59.2 %	6.8 %	5.8 %	5.4 %	13.6 %	9.1 %	$ 44.49
100 mmTons less abatement	33.6 %	6.6 %	6.4 %	6.5 %	23.2 %	23.6 %	$ 59.18

Notes: Table assumes either baseline complementary policy abatement or 100 mmTons less or more abatement.
Ceiling price (C price) is assumed to rise at 5% prior to 2020. After 2020 it is set $60 above the ARP (floor price).
APCR is 174 mmTons.

IV. CONCLUSION

California's cap and trade market is perhaps the most important contribution the state has made to global understanding of the institutions that will help reduce greenhouse gas emissions and climate change. The current program has only been established through 2020, however, and state policymakers are currently discussing the terms for extending the market to 2030. In this paper, we have attempted to inform that policy process by estimating potential outcomes of the cap and trade market under alternative assumptions about market rules and the additional policies for reducing greenhouse gases that are adopted.

Though the details of proposals for extending the market continue to evolve, we have attempted to model market outcomes based on our understanding of the broad outlines of GHG policies at the time of this writing. We have tried to be as transparent as possible about the assumptions made, and provide information that allows readers to infer how changing those assumptions might alter market outcomes.

We have not included estimates of revenues that the program would generate, due to time constraints and uncertainty about policies with regard to free allowance distribution. We intend to include such analysis in future versions of this work.

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APPENDIX

This appendix discusses in more detail the policies for which we adjust the VAR output to arrive at a probability distribution of emissions quantities and prices. For most policies we assume that abatement will fall within a specific range between a more effective abatement case and a less effective abatement case. We then sample from a symmetric $\beta(2,2)$ distribution to create a random draw of abatement for each policy from within our assumed range. Throughout this discussion we characterize "low" and "high" scenarios, with "low" referring to cases in which the result is more likely to be a low allowance price (e.g. more effective abatement), and "high" referring to cases more likely to lead to a high allowance price (e.g. less effective abatement).

A. Zero-Carbon In-State Electricity Generation

Renewable electricity generation is the one major policy where we do not assume a random component to compliance. As in BBWZ, we consider two types of zero-carbon electricity generation, renewables and nuclear power. Our BAU emissions produce an estimate of in-state electricity generation in TWh. We follow the same approach as in BBWZ, subtracting the assumed energy produced from these zero-carbon sources from the specific realization of in-state electricity generation before multiplying the remainder by the estimated GHG emissions intensity of thermal generation. The assumed renewables generation is based on the state's 50% RPS commitment for 2030, and the assumed nuclear generation incorporates the planned closing of Diablo Canyon nuclear power plant in 2024-25. The exact output assumed for these sources is presented in table A2.[11]

B. Electricity Imports

The most recent data for which emissions from electricity imports are available, 2015, indicates 30.7 MMtons per year. Our BAU estimates assume that this number would continue. Roughly 1/3 of that total is associated with the Intermountain Power Plant, owned by LADWP and other smaller California utilities. This plant is scheduled to be converted to natural gas as a fuel source in 2025. We assume that emissions associated with imports from Intermountain continue at their current levels through 2024, are reduced by 25% in 2025, and and are cut to 4.1 mmTons/year from 2026-2030. Of the remaining 20 mmTons/year we assume a range in at one extreme all remaining imports are replaced with zero carbon sources and at the other, roughly half of these imports are replaced with zero carbon sources. This means that the non-Intermountain electricity import emissions can range between zero and 10 mmTons per year. The assumed annual ranges of import emissions are summarized in table A2.

[11]In this analysis, the quantity of renewable generation resulting from the 50% RPS does not adjust with variation in in-state electricity generation. Though we would not expect renewable generation to respond instantaneously to unforeseen increases or decreases in electricity demand and generation, in future analysis, we intend to incorporate some responsiveness of the quantity of generation from renewables to fluctuations in total electricity generation and demand. Because a strict 50% RPS would imply more abatement when electricity generation is higher, this would likely cause somewhat less of the probability distribution to be at the floor or the ceiling.

C. Offsets

It is very difficult to forecast the quantity of emissions obligation that will be met with offsets. At this writing there is still substantial uncertainty about the quantity that will be permitted in a program extended to 2030. There is also ongoing uncertainty about the protocols that will be adopted by the California Air Resources Board, and the number of offsets those protocols will generate. Thus far, about 60 MMtons of offsets have been certified for meeting compliance obligations. We assume a high case in which a total of 90 MMtons are utilized through 2030 and a low case in which total offsets used is 6% of the capped emissions quantity, 307 MMtons. As in BBWZ, all offsets that are allowed under the law and for which the protocol is approved by ARB are assumed to be available at or very near the price floor.

D. Allowance Trade with Canadian Provinces

We are working with very imperfect information about the state of allowance supply and demand in the province of Québec, and further uncertainty about whether Ontario will join the market and, if so, its net supply/demand. Based on discussions with market participants, researchers, and government officials, we assume a high case in which Canadian provinces purchase a net of 250 MMtons from the California market through 2030 and a low case in which California purchases 50 MMtons net from Canadian provinces.

E. Auto Fuel Economy, LCFS and Other Mobile Source Abatement

In its scoping plan, the ARB analysis forecasts that a suite of mobile source strategies will generate 92.5 MMtons of abatement from 2021-2030. We do not scale up these numbers for 2016-2020, because the impacts of many of the policies are not expected to be substantial until the next decade. In the next few years, it seems likely that their impact will not depart significantly from the pre-existing trend that is captured by the VAR. We also note that in 2021 and beyond the scoping plan forecasts assume aggressive improvements in fuel economy, carbon content of fuels, and electric vehicle adoption. So, we take the scoping plan forecast as the low case and 50% of that number as the high case.

Our understanding is that the mobile source strategies forecast in the scoping plan does not include reductions from improved automobile fuel economy and other transportation policies put in place prior to 2015. The California Air Resources Board's EMFAC, model discussed in BBWZ, suggests that improved auto fuel economy will provide an additional improvement in fuel economy, beyond the trend that results from the VAR estimates. The EMFAC model outputs annual values for total GHG intensity from the transportation sector. However the figures in the EMFAC model include the GHG intensity of biofuels, which count as zero under the cap and trade program. Therefore, we have reduced the EMFAC GHG intensities by roughly 10% to remove GHG emissions from biofuels, as shown in table A2. The 30% improvement in GHG intensity from EMFAC between 2016 and 2030 reflects very aggressive assumptions about increased fleet-wide fuel economy and increased share of biofuels and other alternative transportation fuels. We take the EMFAC numbers as the low case and the average (mid-point) of the EMFAC intensities and the transport intensities from the VAR estimates at the high case. As summarized in table 1, these policies, labeled as "Advanced Clean Cars" account for the most significant source of abatement of any of the complementary policies, averaging over 200 MMtons over the next 15 years. It is important to note that these reductions, while present, are represented differently in the ARB's scoping plan analysis. Since these policies pre-date the current scoping plan, they are included in the ARB's reference case and not separately identified as abatement in their results. It is therefore difficult to make a direct comparison of our assumptions to those in the scoping plan for these policies.

F. *Electricity Price Changes Due to Factors Other Than Cap-and-Trade*

Utility and CPUC forecasts suggest that electricity prices are likely to increase substantially more quickly in the next 15 years than they have historically. We use the same assumption as in BBWZ, a 2.15% annual real price increase, through 2030. As in the discussion of price-responsive abatement below, we assume a range of price elasticity of electricity demand from -0.2 to -0.4. This produces a substantial decrease in both electricity consumption and emissions.

G. *Price-Responsive GHG Abatement*

We assume that electricity, natural gas, and transportation fuels quantities will all respond to the price of GHG allowances. For this analysis, we assume full pass-through of the GHG allowance price to end-use consumers.[12] To the extent that some pass-through is reduced through other policies, this will overstate the degree of price-response of GHG abatement. We recognize that output-based free allocation of allowances to some trade exposed industries will dampen their effect on the final product prices, but even in these industries process improvements to lower GHG emissions will still be incentivized by the full price of the allowance.

We assume that the elasticities of demand for electricity and transportation fuels are in the range of -0.2 to -0.4. While some estimates of the elasticity of demand for transportation fuels are somewhat higher than -0.2 to -0.4, such estimates include changes in vehicle choice behavior. Abatement from such change in fleet composition are already reflected in the auto fuel economy adjustments discussed above, so use this range. For natural gas, we assume the demand elasticity is in the range of -0.4 to -0.6. These ranges of elasticities form the high and low cases that are the support of the distribution from which each price-responsive abatement quantity is drawn.

These are higher than the elasticities assumed in the primary analysis in BBWZ, because we are now considering a longer timeframe. Some estimates of the long-run elasticity of demand for each of these energy sources suggest more elastic demand. Those estimates, however, generally include in price elasticity of demand

[12]For transportation fuels, we assume full pass-through of the GHG cost of tailpipe emissions, but no pass-through of GHG cost from refinery emissions due to output-based free allocation.

for a given energy source the response of switching to other fossil fuel energy sources. In contrast, we are interested here primarily in changes that reduce the consumption of all GHG-emitting energy.

We depart from BBWZ in one important way that we believe improves on the previous estimation approach. In calculating the price-responsive GHG abatement, BBWZ assumed that the equilibrium price calculated for the aggregate (over time) market would be the price to which demand responds in each year. In reality, the price in each year will reflect a weighted average of the probabilities of different equilibrium outcomes. So, price will evolve over time as new information is learned, eventually ending at the aggregated equilibrium price.

A full dynamic model of this process would be a large and complex undertaking, which we do not attempt here. Instead, for each of the 1000 random draws, we assume a linear price path from 2018 to 2030. The details of this approximation are as follows: We begin by creating a probability distribution of the overall market equilibrium under the assumption from BBWZ that for each draw the GHG price to which demand will respond in every year is the 2030 equilibrium price associated with that draw, discounted back to each year at a 5% real discount rate. From this price distribution we create a price for 2018 that is the probability-weighted average of the (discounted) 2030 possible price outcomes. For each draw, we then assume that the price to which demand response follows a linear path from this 2018 price to whatever equilibrium price results from that draw. This creates a new distribution of probabilities for prices in 2030, which in turn creates a new price in 2018 that reflects the probability-weighted average 2030 outcomes. We then recalculate the linear price paths for each draw. This iterative process converges quickly so that the price-responsive abatement in response to these price paths create a distribution of 2030 equilibrium prices that, after discounting, is very close to the 2018 price that we assume begins the linear price path. This implies that all price paths to 2030 begin at the same 2018 level, with some increasing to the price ceiling, others decreasing to the price floor, and others ending at some price in between the floor and ceiling. This has a small effect on the expected level of price-responsive abatement, but substantially reduces the variance of price-responsive abatement compared to assuming that the price in every year is the (discounted) final year price.[13]

[13] We carry out this price responsive demand analysis beginning in 2018, because price response for 2016 has already occurred, and much of the price response for 2017 will have occurred by the time the legislation and rules for the extension are finalized. Abatement quantities for 2016 and 2017 are based on the floor prices for each of those respective years.

Table A1—Summary Statistics of Data for Vector Autoregression

	mean	S.D.	min	max	year min.	year max.
California Elec. Generation (TWh)	195.5	13.6	166.1	220.1	1991	2006
California Hydro. Gen (TWh)	33.4	10.5	14.0	51.7	1992	1998
Vehicle Miles Traveled (Billions)	305.3	27.0	258.0	335.0	1991	2015
Industry, Natural Gas & Other Emissions (MMT CO2e)	113.8	4.6	106.6	123.9	1995	1998
Gross State Product (Nominal $Trillion))	1.52	0.54	0.77	2.48	1990	2015
Wholesale SF Gasoline Price (Nominal cents/gallon)	172.17	74.03	95.80	306.05	1990	2012
In-state Elec. Thermal Intensity (tons/MWh)	0.444	0.062	0.364	0.581	2012	1993
Vehicle Emissions. Intensity (tons/1000 VMT)	0.523	0.028	0.468	0.554	2015	1992

Note: Data are for 1990-2015

Table A2—Drivers of Exogenous Abatement Sources

	Zero-Carbon Power		Electricity Imports		Transport Intensity	
Year	RPS GWh	Nuclear GWh	Half Gas mmTons	Low Gas mmTons	Raw EMFAC	without biofuels
2016	52918	17530	26.4	17.7	0.533	0.480
2017	57816	17530	26.4	17.7	0.521	0.469
2018	62715	17530	26.4	17.7	0.509	0.458
2019	67614	17530	26.0	16.6	0.496	0.447
2020	72513	17530	26.0	16.6	0.484	0.436
2021	77411	17530	20.5	10.3	0.471	0.424
2022	82310	17530	20.5	10.3	0.458	0.412
2023	87209	17530	20.5	10.3	0.443	0.399
2024	92108	15339	20.5	10.3	0.431	0.388
2025	97006	4383	20.5	10.3	0.418	0.376
2026	101905	0	19.0	7.2	0.407	0.366
2027	106804	0	17.4	4.1	0.397	0.357
2028	111703	0	17.4	4.1	0.388	0.349
2029	116601	0	17.4	4.1	0.380	0.342
2030	121500	0	17.4	4.1	0.374	0.336

Table A3—Summary Statistics of Simulated VAR Variables and Emission

Year	California Electricity net of Hydro Twh	Vehicle Miles Traveled Million Miles	Nat. Gas, Ind. & Other MMT	Gasoline Price $2012	Gross St. Product $2012 Trillion	Therm. Intensity tons/ MWh	Trans. Intensity tons/1000 Miles	Broad Scope Emis. MMT	Cum. Emis. MMT
2013	186.6	327.1	111.1	2.44	2.39	0.384	0.474	347.5	149
	(23.3)	(31.3)	(15.0)	(1.32)	(0.49)	(0.072)	(0.044)	0.0	0
2014	189.0	330.7	110.8	2.48	2.46	0.378	0.472	343.8	291
	(24.6)	(32.6)	(15.3)	(1.36)	(0.51)	(0.073)	(0.045)	0.0	0
2015	191.4	334.5	110.6	2.52	2.52	0.373	0.469	340.3	632
	(25.9)	(34.1)	(15.7)	(1.43)	(0.54)	(0.073)	(0.046)	0.0	0
2016	195.6	338.1	109.3	2.37	2.55	0.357	0.469	343.1	975
	(30.7)	(8.4)	(6.7)	(0.89)	(0.16)	(0.033)	(0.024)	(13.5)	(14)
2017	195.3	341.2	108.9	2.46	2.60	0.354	0.466	341.0	1316
	(24.4)	(12.0)	(9.5)	(1.92)	(0.26)	(0.041)	(0.029)	(16.2)	(27)
2018	197.8	344.6	108.5	2.51	2.66	0.350	0.463	340.2	1656
	(25.8)	(14.7)	(10.9)	(2.37)	(0.31)	(0.045)	(0.032)	(19.0)	(44)
2019	200.6	348.1	108.1	2.58	2.73	0.346	0.461	339.5	1995
	(27.9)	(17.2)	(11.8)	(2.71)	(0.35)	(0.048)	(0.035)	(21.6)	(63)
2020	203.5	351.9	108.0	2.62	2.79	0.341	0.457	338.9	2334
	(29.0)	(19.5)	(12.5)	(2.54)	(0.40)	(0.051)	(0.037)	(23.6)	(85)
2021	206.0	355.8	107.6	2.64	2.86	0.338	0.455	338.5	2673
	(30.4)	(21.7)	(13.4)	(2.25)	(0.43)	(0.054)	(0.039)	(25.8)	(109)
2022	209.1	359.7	107.3	2.72	2.93	0.334	0.453	338.3	3011
	(32.9)	(23.8)	(14.1)	(2.49)	(0.47)	(0.057)	(0.041)	(27.9)	(134)
2023	211.8	363.7	107.0	2.73	3.00	0.330	0.450	337.9	3349
	(33.0)	(25.6)	(14.9)	(2.30)	(0.51)	(0.059)	(0.043)	(29.3)	(161)
2024	215.1	367.7	106.6	2.80	3.08	0.326	0.448	338.4	3687
	(35.7)	(27.6)	(15.5)	(2.19)	(0.55)	(0.062)	(0.044)	(31.7)	(190)
2025	217.8	371.8	106.2	2.87	3.15	0.322	0.445	341.5	4029
	(37.0)	(29.7)	(16.2)	(2.31)	(0.59)	(0.065)	(0.045)	(33.4)	(221)
2026	221.5	375.6	105.8	2.94	3.22	0.318	0.443	342.6	4371
	(38.6)	(31.8)	(16.9)	(2.35)	(0.63)	(0.068)	(0.047)	(35.2)	(254)
2027	223.1	379.6	105.4	2.99	3.30	0.314	0.441	341.9	4713
	(39.1)	(33.7)	(17.5)	(2.36)	(0.66)	(0.069)	(0.048)	(36.5)	(287)
2028	225.5	383.9	105.3	3.02	3.39	0.311	0.439	341.8	5055
	(40.1)	(35.8)	(17.9)	(2.40)	(0.72)	(0.072)	(0.050)	(38.6)	(322)
2029	229.4	388.1	104.9	3.09	3.48	0.306	0.437	342.1	5397
	(42.4)	(37.6)	(18.5)	(2.59)	(0.77)	(0.075)	(0.052)	(40.2)	(359)
2030	232.7	392.5	104.6	3.13	3.56	0.304	0.435	342.2	5739
	(45.5)	(39.9)	(19.3)	(2.72)	(0.82)	(0.077)	(0.053)	(42.5)	(398)

Note: Estimates are mean values of 1000 draws, values in parenthesis are the standard deviations of 1000 draws.