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WORKING PAPER

Quantities with Prices

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RESOURCES FOR THE FUTURE

Quantities with Prices

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Abstract

First-best environmental policy in the presence of uncertainty is often posed as a choice of price versus quantity instruments. In practice, climate policies are incremental and multi-faceted, combining economic and regulatory approaches, and determined with limited geographic scope that does not balance global benefits and costs. Quantity emissions targets are typically preferred, designed on principles derived from the first-best framework that apply imperfectly to the partial equilibrium policy setting. This paper recognizes and evaluates the emergence of price responsive emissions allowance supply schedules in existing trading programs. We use simulation modeling and laboratory experiments to explore different forms of a supply schedule, with application to the Regional Greenhouse Gas Initiative trading program. We find that a price responsive supply schedule usefully shares the risks and benefits of unexpected outcomes with respect to emissions control costs between economic and environmental interests, and preserves incentives for companion technology and energy policies.

Key Words: cap and trade, climate policy, greenhouse gas, climate change, electricity

JEL Classification Numbers: Q48, Q54, Q58

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1. Introduction.

Two central principles of environmental economics are (1) that economically efficient policies to limit harmful emissions should be designed in a way that equates the marginal benefits of limiting emissions to the marginal costs of doing so and (2) that policy should be set at a geographic scale that captures all relevant contributors to the problem of concern (Oates 1999). In the case of global climate change, this first-best set of principles suggests that an optimal greenhouse gas policy would be global in design. In the early years of global climate negotiations coordinated by the United Nations such an approach was embraced by the majority of nations in the Conference of Parties and this support was reflected in the nearly global cap-and-trade system in the 1995 Kyoto Protocol. However, in practice it proved impossible to achieve the consensus necessary to implement such program. Instead, at the UNFCCC meeting in 2016, the countries of the world opted for a different approach in the Paris Accords. This new climate agreement codifies a country by country approach under which each nation makes a pledge establishing national emissions reduction goals and declaring policies for reaching those goals. In some parts of the world, including the United States and Canada, the decentralized approach to climate policy extends to the subnational level in many cities, states and provinces, with cap-and-trade programs in the Western Climate Initiative including California, Quebec and Ontario, and in the Regional Greenhouse Gas Initiative involving a group of northeast states, as well as a carbon tax in British Columbia.

A third lesson from environmental economics is that identifying a globally optimal policy for limiting pollution requires the choice of a control variable: either prices or quantities

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(Weitzman 1974). Most, but not all, of the evidence favors a price based approach, particularly in the case of stock pollutant with relatively flat marginal benefits from reduced emissions (Hoel and Karp 2001, Newell and Pizer 2003). Nonetheless, most of the national and subnational programs have adopted a cap-and-trade approach and, while the level of the emissions cap determines the marginal cost of reductions, that level of regulatory stringency has not been calibrated to global economic measures of the marginal damage from incremental emissions. Instead emissions caps are determined as part of scientifically informed regulatory and political negotiations that occur primarily within the jurisdiction, not between jurisdictions. Hence, the emissions allowance quotas in existing programs do not align with the marginal social cost of carbon emissions. Importantly, the quota is typically a fixed quantity of allowable emissions determined through this negotiation, a design that derives from first-best theory, but does not necessarily apply in a partial equilibrium policy context. Nonetheless, the basic principle of cost effectiveness is preserved in the allowance market equilibrium that balances marginal benefits (the allowance supply schedule) with marginal costs of emissions reductions (the demand for emissions allowances).

While this market based approach supports cost effective outcomes, the typically perfectly inelastic supply (fixed quantity) of emissions allowances in these markets at least in periods between adjustments to the program offers a limited ability for the market to respond to new information including lower or higher than expected emissions control costs and demand for allowances, as well as the resolution of uncertainty over time. In most commodity markets, supply curves have a less than infinite slope; as the amount of the commodity that enters the market decreases (increases) with decreases (increases) in the market price. If demand falls, thereby decreasing market prices, less of the good is brought to market which tends to buffer those price decreases; however, in emissions allowance markets, typically only the allowance price can adjust to new information. In some allowance markets concerns about high prices have led to the establishment of absolute price caps or, more commonly, cost containment reserves that introduce a limited quantity of additional allowances at specified price levels to buffer unexpected price spikes. Many programs that use auctions to distribute emissions allowances initially also have a price floor below which no allowances will be sold. But in these markets, supply curves remain perfectly inelastic between these two price points.

The standard design for emissions markets is derived from the seminal formulation of a global optimization problem with the choice of the control variable to be either prices or quantities, with some authors (described below) suggesting hybrids and adjustment mechanisms. The innovation in allowance markets that we observe and characterize here is the introduction of a price responsive supply curve to allowance markets replacing a perfectly inelastic supply function. Such a supply schedule embodies instructions from policy makers to the market and allows the quantity of allowances supplied and market equilibrium to change with new realizations about program costs resulting from a range of factors. With a price responsive supply schedule, which we describe simply as quantities with prices, the market equilibrium will shift along the supply schedule resulting in a change in price and quantity, as in a standard commodity market.

The perfectly inelastic supply of emissions allowances has several disadvantages for regulators. One is that revenue that can be raised from the auction of emissions allowances is variable; as the price changes the revenue changes in direct proportion. Major carbon emissions trading programs include provisions for reinvesting auction revenues, but planning for such investments is difficult when revenues are highly variable, and these variations have sometimes been described as signals of program failure. A second disadvantage is that all the impact of price fluctuations accrues to the compliance side of the policy ledger, by reducing costs when prices fall and increasing costs when they rise, without any change in the environmental outcome. In practice, the much more prevalent outcome has been for prices to fall below expected levels, in part due to the role of additional measures implemented by other jurisdictions (Burtraw et al. 2018), with the benefits of the price drop accruing strictly to the economy. Hence, a third and related disadvantage from the regulator's perspective is that, because only prices change in response to changing demand for allowances and emissions do not change, the inelastic supply undermines the incentive for individuals and subsidiary jurisdictions within an emissions-capped region to take additional actions to reduce emissions (Goulder and Stavins 2011). However, from a regulator's perspective, if changes in the baseline and especially voluntary action leads to downward pressure on allowance prices, one might expect that action to result in reduced emissions. Indeed, if emission reductions are less expensive than anticipated, one might expect economic behavior to lead to buying more of them, but until very recently this feature has been missing from existing emissions trading programs, rendering them less desirable in the minds of some regulators and environmental advocates.

We envision the policy-determined supply schedule in an emissions trading program to embody instructions to the market from policy makers in the face of uncertainty about costs, innovation, other policies in one's own jurisdiction and policies in other jurisdictions that also will affect these outcomes and the market equilibrium. In this paper we describe a fundamental evolution that is taking hold in emissions trading programs, the introduction of a price-responsive supply of emissions allowances. This approach allows for the general setting in which allowance demand may differ from expectations in either direction (Borenstein et al. 2016).

In section 2 we review the literature, much of which has anticipated adjustments to either a price or a quantity approach to make it more like the other, but for the most part has started with one or the other as a basic model, in contrast to most markets where price and quantity are mutually determined with the supply of a commodity. In Section 3, we compare the conventional vertical supply curve for emissions allowances with a step-wise supply schedule and a continuous schedule. In Section 4 we describe this innovation in the specific context of the Regional Greenhouse Gas Initiative, which recently adopted this approach in what it describes as an "emissions containment reserve." In Section 5, we report simulation modeling of outcomes concerning various formulations for a supply schedule in that context. We quantify the sharing of benefits from a decline in allowance demand between economic and environmental outcomes and observe that the price responsive supply curve helps preserve emissions reductions that are achieved by companion policies enacted by individual jurisdictions within the capped region. We find that auction revenue is expanded under a price-responsive supply curve, even though fewer allowances are sold, making greater revenue available for program-related spending.

In Section 6 we supplement the simulation modeling with laboratory experiments. We find the emissions containment reserve is easy for market participants to understand and does not interfere with the performance of the allowance auction. We also observe that the interaction between demand and supply helps reduce price volatility. In Section 7 we analyze issues associated with the implementation of an elastic supply schedule, before concluding.

2. Literature

Climate science suggests that the emissions reductions necessary to limit the degree of global warming in a meaningful way are substantial and achieving them would require a large transformation of the energy sector and a major shift away from fossil fuels expected to unfold over time. The policy pathway toward this goal is usually manifest in a cap and trade program with a cap on emissions that declines over time. The costs of meeting those caps are highly uncertain, particularly further into the future as policy goals become more ambitious. The early literature dealing with uncertainty in the design of climate policy focuses on situations where marginal costs of achieving emissions targets might turn out to be higher than expected and developing policy features to offer some relief should policy goals prove expensive to attain. Most of these proposals involve a combination of quantity and price mechanisms first discussed by Roberts and Spence (1976). Pizer (2002) is one of the first to consider the combination of policies in the climate regulatory context and shows that combining a price and quantity is more efficient than a price based mechanism alone, including when the policy goals are not set optimally. Aldy and Pizer (2009) discuss various options that have been included in climate policy proposals discussed in the US Congress and elsewhere including a safety valve cap on the price of emissions allowances at which additional allowances enter the markets, a circuit breaker that would stall the rate of decline of an emissions cap if allowance price hits a specified level and establishing an independent board to manage the supply of allowances to keep prices within an acceptable range (Murray et al. 2009). Similar mechanisms are envisioned with respect to how an emissions fee could be adjusted to achieve an emissions goal (Newell et al. 2005, Aldy et al. 2017). Virtually all discussions start from one of the two conceptual approaches, quotas or fees, and explore modifications that make one look like the other or, potentially, offer a hybrid of the two approaches. This construction differs, however, from virtually every commodity market in which the supply of the commodity varies with the equilibrium price obtained in the market.

One cost-related concern is that prices might spike due to short-run factors such as weather or disruptions in fuel supply and this spike could have deleterious effects on the economy. Cap and trade programs typically include features that can help to mitigate the likelihood of price spikes. One approach is allowing temporal banking and borrowing of allowances. The early literature on banking focused on smoothing temporal fluctuations to minimize the present discounted value of complying with regulatory goals over time and did not discuss the issue of uncertainty (Cronshaw and Kruse 1996, Rubin 1996, Kling and Rubin 1997). More recently, Fell et al. (2012c) consider a situation with uncertainty about compliance costs and show that cap and trade with banking can replicate the efficiency of a price based policy in the climate context. Recognizing that policies are likely to be updated over time and that allowance banking enables intertemporal arbitrage, Pizer and Prest (2016) show that a quantity based policy can be superior to a price based one given that arbitrage over time is not possible with a price based policy. Offsets from outside the regulated sector (or associated with mitigation of emissions of non-CO_2 gasses) are another mechanism that can help to reduce the costs of compliance and the likelihood of short term prices spikes, although the supply of offsets is also uncertain and may be correlated with other compliance costs, which could amplify price fluctuations (Fell et al. 2012b).

Throughout most of the literature and all that we reference above, the economic issue is described as a design problem from a system (global) perspective. However, the Paris accord places hope for progress on international climate policy on bottom-up, loosely coordinated actions of independent jurisdictions, wherein decision makers have even less information about benefits and costs of mitigation and the mitigation efforts that will be taken by other jurisdictions, but where they can be expected to have some success in coordinating actions (Barrett 2016). As climate policies have evolved in fairly small geographic markets, aligning policies and program designs can be the precondition for greater linking across programs

(Burtraw et al. 2013). Linking may help mitigate price volatility through broadening markets, mitigate concerns about competitiveness between jurisdictions (Jaffee et al. 2009), and enable greater environmental ambition by keeping costs low (Bodansky et al. 2015) especially where independent programs yield different stand-alone allowance prices (Flachsland et al. 2009).

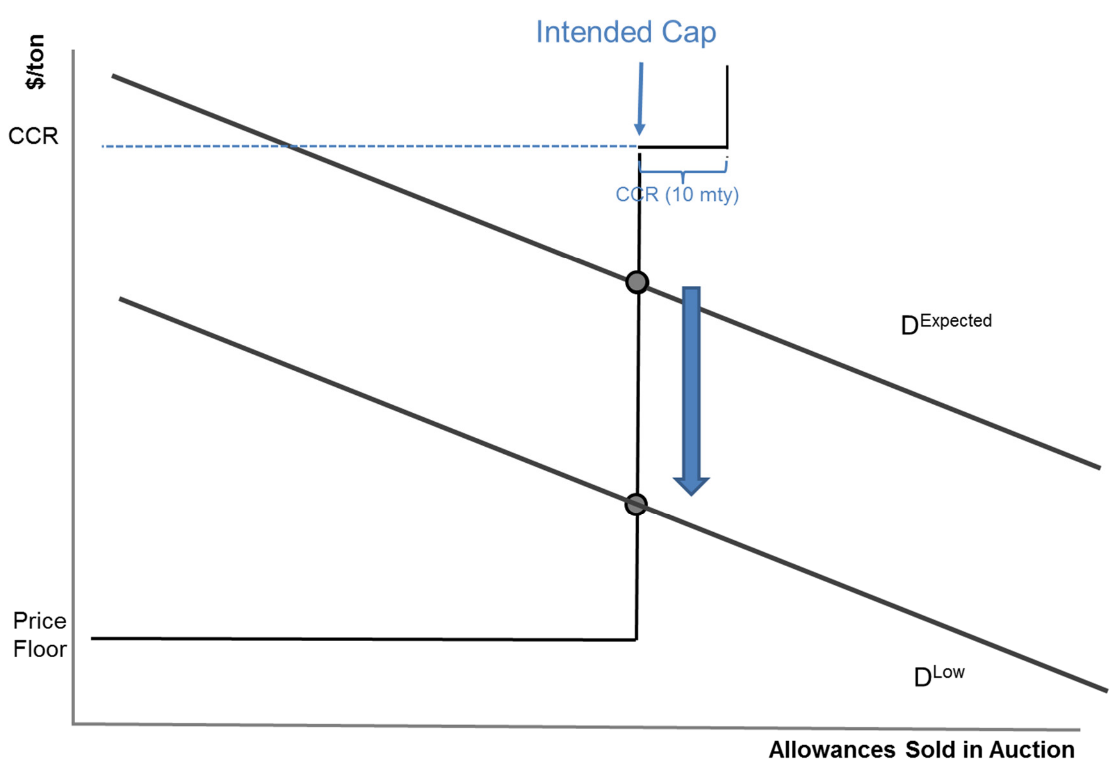
While the literature is overwhelmingly about shielding markets from high cost shocks, experience in virtually every cap and trade market suggests that lower than expected prices are a more likely outcome. These low price outcomes result primarily from lower than expected demand for allowances. One mechanism that has been suggested for dealing with this approach is a price collar that incorporates both a floor on allowance prices and a ceiling. Burtraw, Palmer and Kahn (2010) show that such a mechanism can be useful as a way to support prices and thereby maintain incentives for investment in clean technologies, and Grüll and Taschini (2011) provide an analytic exposition. Fell et al. (2012a) examine a soft price collar in which the prices are enforced incompletely with a limited volume of additions or subtractions from the expected cap. They find that increasing the size of the reserve of allowances lowers costs, but with a diminishing effect as the reserve is expended. Hence, although increasing the size of the reserve would, if triggered, increase emissions, the emissions uncertainty associated with changes to the cap can be limited while achieving considerable assurance about overall cost. Some authors have dismissed the idea of a price collar in the context of free allocation because it suggests a contingent property right, which would be taken away or repurchased by the government if prices fell and allowances were retired. However, over time, cap and trade program design has migrated to auctioning of allowances in the North American and European trading programs, and that makes possible the use of a reserve (minimum) price in the auction to enforce a floor price in the market. This approach to enforcing a price floor can be implemented even with free allocation of allowance value to compliance entities, where those who are awarded free allowances are required to consign some or all of them to be auctioned and then are the recipients of the revenue associated with their portion of the allowances sold at auction (Burtraw and McCormack 2016). Auction reserve prices are also the mechanism through which additional allowances are brought into the program when allowance prices reach price ceiling triggers.

3. Price Responsive Allowance Supply

Existing programs have incorporated lessons from the economics literature on cost containment into their policy designs. All of the North American carbon markets have introduced hard price floors, meaning that no allowances sell in the auction below the reserve price, thereby constraining the supply and supporting the market price. Price ceilings, or cost containment reserves (CCRs), to date are “soft” meaning that a limited number of additional allowances are available at specified prices, although California has recently amended its program to include a hard price ceiling beginning in 2021. In the price range between the floor and cost containment reserve there is no effect on price when demand for emissions allowances changes. Figure 1 illustrates how lower-than-expected allowance demand affects allowance market clearing prices and sales volume in the context of the current market design in the Regional Greenhouse Gas Initiative. As illustrated, low demand reduces allowance prices without having any effect on the number of allowance sold at auction, and therefore, no effect on emissions.

The figure illustrates a dilemma. Additional actions may be taken by cities, states, companies, or individuals in the region to reduce emissions associated with electricity consumption based not on the price of CO_2 emissions but for other environmental reasons. These additional efforts lead to an economic benefit for all the states in the region in the form of lower allowance prices, but they do not yield additional emissions reduction benefits. We refer to this as the "waterbed effect" because reducing emissions in one place simply makes available allowances to emit CO_2 in another place.

Figure 1. Supply Schedule with Price Floor and Cost Containment Reserve



A price responsive supply schedule would recover some of the additional contribution to emissions reductions associated with a decline in the equilibrium price in the auction. In most commodity markets, when the price of a good falls, less of that commodity enters the market. To accomplish this outcome in an allowance market the supply schedule would establish a price step or multiple steps, or a continuous ramp, above the price floor. Each step would be associated with a quantity of allowances that would not enter the market for a price below that price step. This feature is different from the price floor that applies to all allowances. A price step would apply to a specified quantity of allowances and could coexist with the price floor, below which no allowances would sell in the auction. There could be multiple price steps associated with specified quantities, forming a discrete price schedule above the price floor, or there could be a continuous schedule.

Figure 2 illustrates the influence that a supply schedule with a single step below the anticipated equilibrium price would have on the market if the demand for emissions allowances fell from its expected level to a low level. In this case the schedule would reduce the number of allowances entering the market, and the reduced supply would support the allowance price. As illustrated, the equilibrium allowance price would settle on the price step. If demand were even less, the equilibrium price would fall below the middle price step.

A supply schedule with multiple price steps could be implemented with specified prices and quantities of allowances associated with each price step. Figure 3 displays the same demand curves with several price steps. If demand fell to a low level, the equilibrium price in the market could fall below the highest price step to the second one, or potentially fall even further. One of the characteristics of a multi-step schedule is that the chance that any one step would ultimately determine the allowance price is less than under a single-step schedule. A continuous supply schedule would make supply even more responsive to incremental changes in allowance demand.

The price responsive supply schedule would help mitigate the waterbed effect because it enables a sharing of the benefits of falling allowance demand between economic savings and emissions reductions as some of the downward pressure on prices is translated into a reduction in the supply of allowances. This sharing of benefits would help preserve the incentive for policy initiatives by state and local governments, and voluntary actions by businesses and individuals, to pursue emissions reductions in addition to and beyond those required by the RGGI cap.

The price responsive supply schedule also might help the allowance market function more efficiently. The large vertical portion of the allowance supply schedule makes possible large unanticipated changes in allowance prices that can affect incentives to invest in clean sources of generation or energy efficiency that would help reduce emissions on an ongoing basis.

If investors make decisions based on their assessment of the probability distribution over future prices, then the price-responsive supply schedule would remove part of the risk of low prices.

In addition, when prices fall, compliance entities may purchase allowances in excess of their current compliance obligations in anticipation of a strengthening of the cap during a future program review. The price responsive supply schedule might proactively reduce the incentive to acquire large private banks while lessening the need for large cap adjustments during program review, as has occurred in some programs.

Figure 2. A Price Responsive Supply Schedule with One Step and Changes that Result from a Low Demand for Emissions Allowances

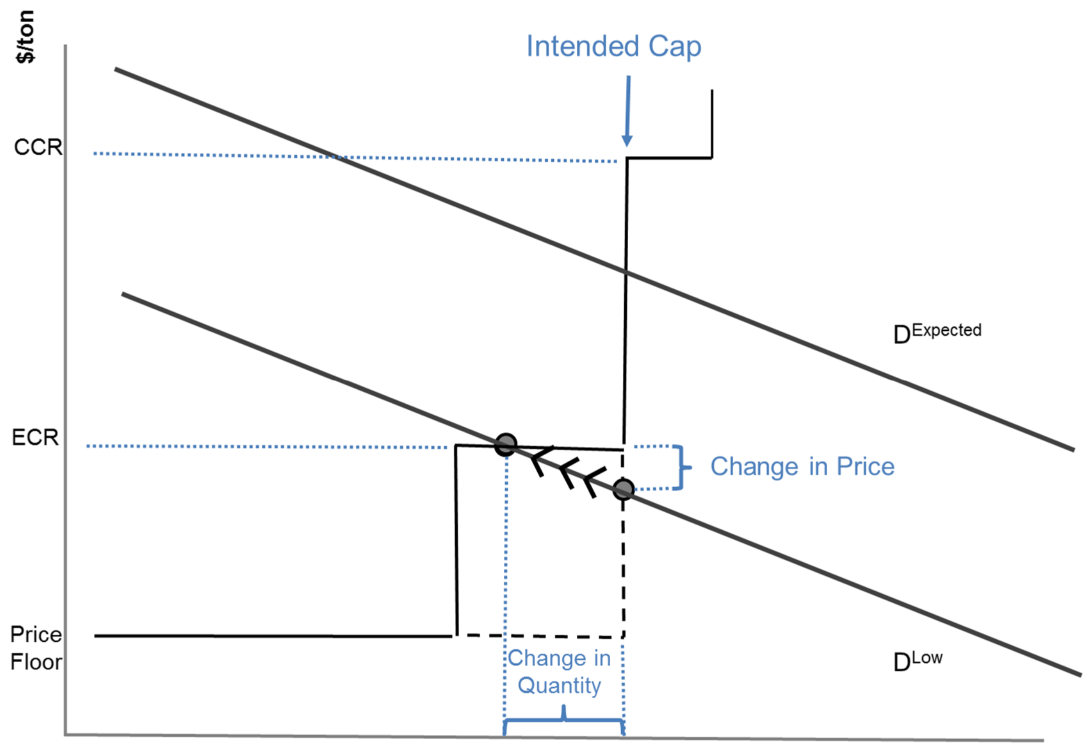
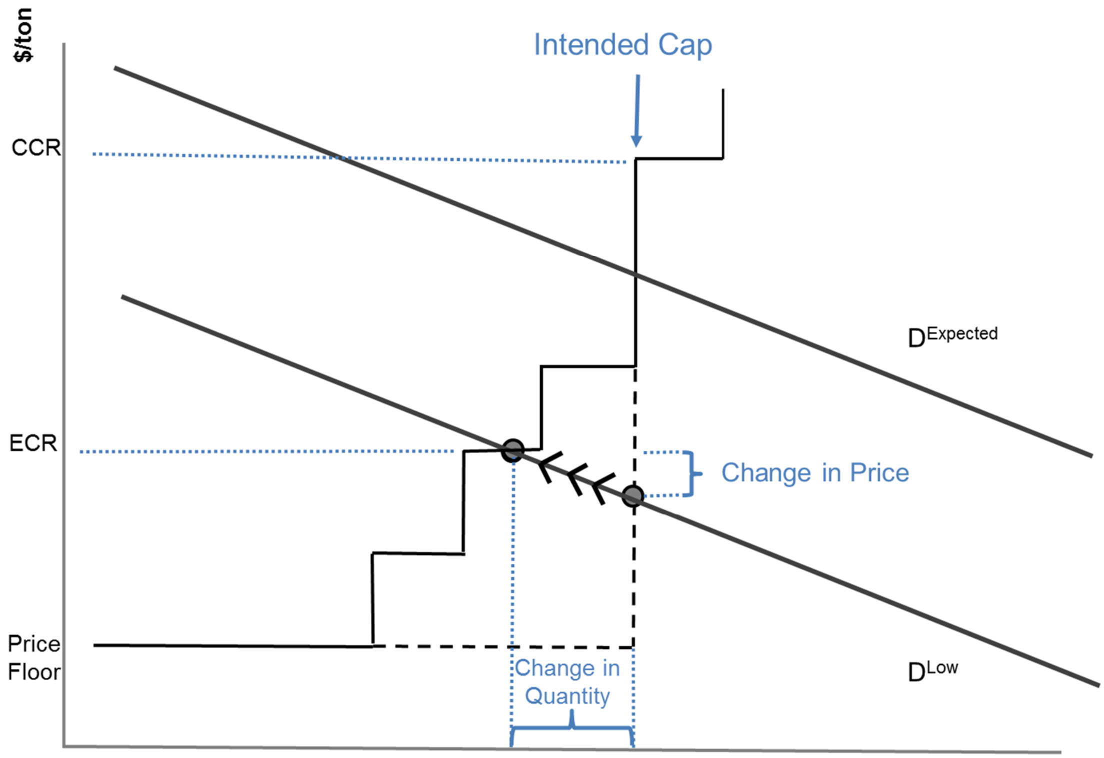


Figure 3. A Price Responsive Supply Schedule with multiple steps and changes that result from a low demand for emissions allowances



4. Implementing Quantities with Prices: An Example from RGGI

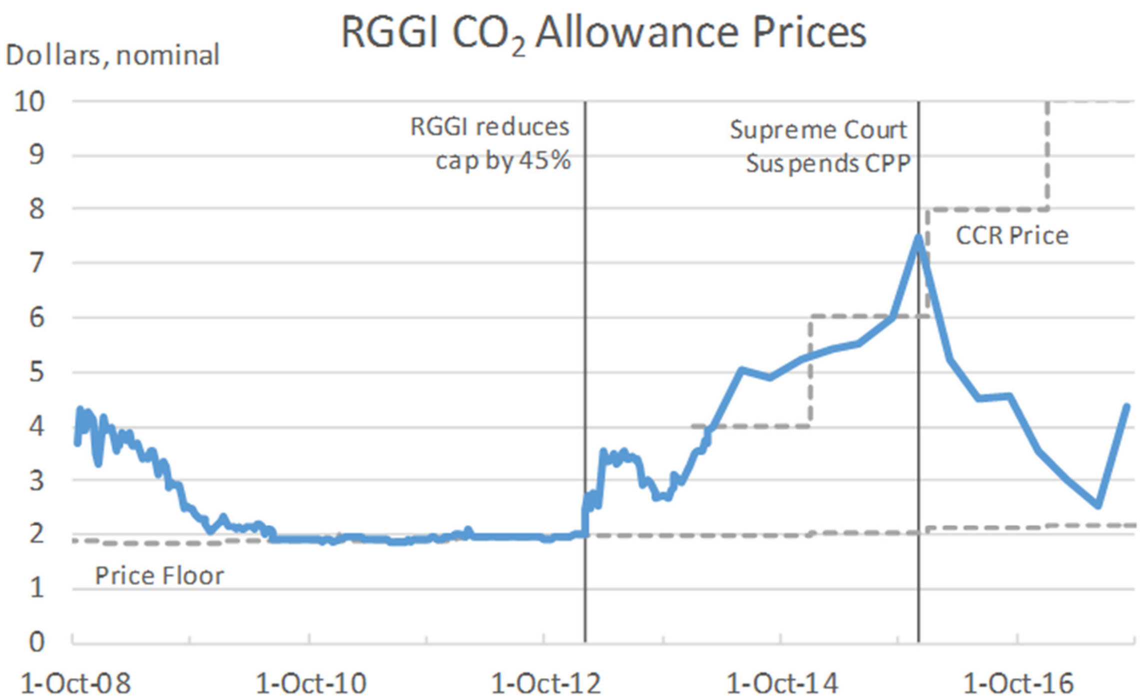
While most of the economics literature on policy design features to ameliorate unexpected cost outcomes in emissions cap and trade programs has focused on mitigating adverse effect of high side cost spikes, most of the experience in allowance markets has been that allowance prices end up being lower than expected. This experience and the factors that contribute to it are described in the context of several existing allowance trading programs in Burtraw et al. (2018) and in the context of the EU Emissions Trading System specifically by Ellerman and Buchner (2008) and Koch et al. (2014). Murray and Maniloff (2015) look at emissions reductions within the first several years of the RGGI program and find that unanticipated changes in the economy and in fuel prices and other energy policies, including policies promoting energy efficiency, account for roughly half of the emissions reductions in the RGGI region after the program went into effect, contributing to lower than expected demand for allowances and lower than expected allowance prices.

Both low and high-side cost containment have been features of RGGI since its inception in 2009. As the first cap-and-trade program for CO_2 emissions anywhere in the world to auction almost all of its emissions allowances, the RGGI program includes both an auction reserve price to help support program based emissions reductions in the face of lower than expected costs and a cost containment reserve.[1] Over time, the rules of RGGI have evolved and continue to do so. A 2012 Program Review led to a reduction in the trajectory of the emissions cap and the retirement of all allowances that were not sold at previous auctions.

Figure 4 shows the clearing price results of all 36 allowance auctions beginning with the first two auctions that occurred just prior to the cap coming into effect in 2009 plotted on top of the quarterly CO_2 emissions outcomes in the RGGI states. The graph reveals that after 7 initial auctions where prices cleared above the floor, auctions cleared at the floor price for eleven quarterly auctions. Then, prices started to head upward beginning in 2013, after the 2012 Program Review had reduced the number of allowances that would enter the market beginning in 2014. This was also the beginning of the second term of the Obama Administration when EPA started to formulate the Clean Power Plan to regulate CO_2 emissions from the electricity sector under the Clean Air Act. Anticipation of these regulations and the role that RGGI allowances could play in Clean Power Plan compliance likely contributed to increased allowance demand and clearing prices rose high enough to trigger the cost containment reserve in both 2014 and 2015 before falling again, starting in 2016. Thus, both the price floor and the price ceiling have been called into action during the first 9 years of the program.

[1] In 2017, the RGGI auction minimum reserve price as set at $2.15 per ton and it is scheduled to rise at 2.5 percent per year going forward. The cost containment reserve was set to introduce 10 million additional tons at a a price of $10 per ton in 2017 and also is scheduled to rise by 2.5 percent per year thereafter. As a result of the 2016 program review, beginning in 2021 the cost containment reserve will be set at 10 percent of the emissions cap level (roughly 7.5 million tons in 2021 and declining at 227.5 thousand tons per year thereafter) triggered at an initial price level of $13 per ton that grows at 7 percent per year thereafter.

Figure 4. Allowance Prices in RGGI



Note: Auction prices are used where market prices are not available.
Sources: Thomson Reuters; RGGI.

Substantial declines in the price of natural gas over the past decade as a consequence of the introduction of fracking technology and the resulting abundance of supply have reduced reliance on coal-fired generation and thus lowered demand for CO_2 emissions allowances. There is also uncertainty about how much electricity demand will grow over time and demand growth has been slowing relative to past trends and to expectations for several years. The economic recession reduced demand for electricity and emissions fell accordingly, but electricity demand has remained low as the economy has recovered. Operation of the existing nuclear fleet is also subject to uncertainty as low prices for wholesale electricity reduce nuclear profitability. Uncertainty about closure dates of certain large nuclear plants in the region affect the anticipated contribution of this non-emitting source to the generation mix. State and federal policies and programs to support renewable technologies also put downward pressure on emissions allowance prices, as do programs to promote energy efficiency in buildings. Uncertainty about future regulatory changes directed at CO_2 emissions, particularly at the federal level, may also reduce demand for allowances. All of these factors taken together suggest that the possibility for a slack emissions cap in RGGI is real.

As a result of its recently completed 2016 program review, RGGI is making some important program changes to take effect at the beginning of 2021. One of these changes involves introducing an additional level of price responsiveness in the allowance supply curve through the introduction of a single step allowance supply schedule, which has been termed an emissions containment reserve (ECR) in the context of the RGGI program. In the case of RGGI this ECR will withdraw up to 10 percent of the allowances from the market if the auction price falls at or below a trigger price of $6.00 in 2021, with that price rising at 7 percent per year in subsequent years.[2]

The implementation of a price responsive supply curve is simple and reproduces the mechanism of the current price floor and the cost containment reserve, but with additional price levels. For our analysis of the RGGI context in the next section, we adopt the language that RGGI uses to describe the addition of an intermediate price step and refer to this particular intermediate price step feature as the ECR. All of these mechanisms — the price floor, CCR and ECR — have minimum prices that are implemented as specific reserve prices in the auction, that is a minimum acceptable bid on a specified quantity of allowances. This is a familiar feature on platforms that sell goods in an auction setting. For example, one can observe the same kind of feature on eBay, where one can specify a minimum acceptable bid for items that are posted for sale.

5. Simulating the Emissions Containment Reserve (ECR) in the RGGI Program

We use the RGGI program as a laboratory to study the effects of a price-responsive supply curve, focusing exclusively on the empirically relevant prospect of a decline in allowance prices in RGGI, and the introduction of what RGGI terms an ECR on the allowance market and electricity market outcomes when allowance demand deviates from expectations. The RGGI program is represented in the Haiku electricity market model (Paul et al. 2009), which has been used in numerous other analyses of economic proposals and regulatory policies (e.g. Mignone et al. 2012). The model provides a partial equilibrium economic representation of investments and retirement of generation resources in 26 regions in the 48 contiguous US states linked by transmission capacity, and operation of the electricity system during selected years over three seasons and four times of day through 2035. Fuel supply and electricity demand respond to

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[2] Currently Maine and New Hampshire are not participating in the Emissions Containment Reserve so will not be witholding any of their allocated allowances from the auction show prices fall below the ECR trigger price.

equilibrium prices. The model is calibrated to the AEO 2016 projections of electricity demand, retail prices and gas fired generation.

RGGI completed a program review in December 2017 that altered the path of the emissions caps beginning in 2021.[3] Our base case assumptions in the simulation model are comparable to the current design of the RGGI program , and to the ICF assumptions used in the Integrated Planning Model (IPM) simulations performed on behalf of RGGI in November 2016.[4] The Haiku model achieved comparable emissions allowance prices as IPM for our reference case scenario that included an annual reduction in the emissions cap equal to 3.5 percent of 2020 cap, or 2,736,132 million tons each year between 2021 and 2030.[5]

The path of allowance prices anticipated by the IPM model in November 2016 is illustrated in the top line in Figure 5. In 2020, the price was projected to be about $7 per ton, rising to about $9 per ton in 2026. However, in the April 2017 update to its modeling for RGGI, the allowance price projected by IPM fell to near the auction price floor in 2020, remaining near the floor for the subsequent decade, as illustrated in the bottom line. Important to our analysis, the changes that contributed to this update include changes to natural gas price projections (updated from AEO 2015 to AEO 2017), updated regional electricity demand projections and projections for cost and performance of renewables, and anticipation of additional renewable imports from Quebec and Ontario. These changes illustrate how, in just six months, unanticipated changes in market factors can influence the price of emissions allowances by changing market demand. Once determined through regulatory negotiation, the supply of allowances in trading programs is fixed until and if it is revised during a subsequent program review, but the demand for allowances can change quickly.

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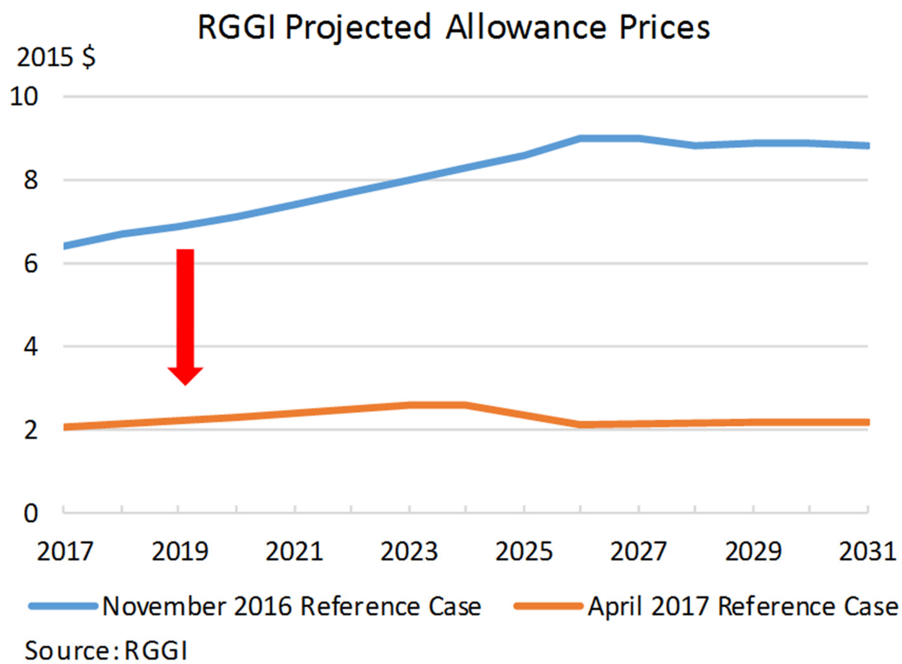
[3] The Model Rule Update includes adjustments to the size and structure of the cap and apportionment to states, adjustments to the cost containment reserve, and the introduction of an emissions containment reserve. See: https://rggi.org/docs/ProgramReview/2017/12-19-17/Summary_Model_Rule_Updates.pdf.

[4] http://www.rggi.org/design/2016-program-review/rggi-meetings.

[5] This schedule is based on the 2020 cap before an adjustment that was approved in 2012 to account for the large privately held bank of emissions allowances. That adjustment reduced the cap from 2016 through 2020, culminating in a 28 percent reduction in 2020 from 78,175,215 tons to 56,283,807 million tons. In addition, a bank of publicly state-held allowances that did not sell when prices were at the price floor was permanently retired.

Figure 5. IPM Projections of RGGI Prices Changed with New Assumptions



The reference case in the Haiku model has a cost profile similar to that anticipated in November 2016 by IPM. In modeling the 3.5 percent annual reduction in the allowance cap, we project an allowance price in 2020 of $8.10 per ton that rises at 5 percent per year over the subsequent decade, reflecting the opportunity cost of holding emissions allowances in the allowance bank. We assume the allowance bank is exhausted in 2030. The cost containment reserve is not relevant at the range of prices we explore. Allowances that are not sold due to the implementation of the ECR are retired.

5.1. Modeling Unanticipated Outcomes in the Electricity Market

We explore factors that could put downward pressure on allowance prices in the same way that the factors modeled by IPM in April 2016 did. We acknowledge that unknown factors outside the model are likely to have important additional uncertain influences on allowance demand that influence the allowance price. In our modeling, we describe six possible unanticipated outcomes in three conceptual groups.

Secular Outcomes

- Low Demand Growth: electricity demand growth is based on the AEO 2016 “Low economic growth” case which has lower demand nationally than in the AEO Reference case

- High Natural Gas Prices: natural gas supply is based on the AEO 2016 “Low oil and gas resource and technology” case which has higher natural gas prices than the AEO Reference case

Policy Outcomes

- More Energy Efficiency: $2.5/MWh system benefit charge funds energy efficiency programs for electricity end-users in 2020 and thereafter in all RGGI states
- Expanded RPS: RPS targets are 5% above currently stipulated targets in 2020-2024 and 10% above in 2025 and thereafter in all RGGI states

Resource Outcomes

- Hydro: expanded hydro (1050 MW @ 100% capacity factor) power imports from Quebec to New England
- Nuclear: delayed retirement of nuclear facilities that are otherwise scheduled for retirement during the 2020s

Each of these potential unanticipated outcomes is modeled separately and in groups of two (as indicated under the headings above), in groups of four (combining pairwise combinations of the headings above) and altogether as one group. The RGGI allowance price outcomes for the year 2020 with no ECR are reported in Table 1. The numbers in the first row show the allowance prices when each scenario is modeled separately. The other rows show results of the scenarios in different combinations.

Table 1. Allowance Prices [$/ton] with no ECR in 2020 Under Various Unanticipated Outcomes (2011 dollars)

<table>
<tr><th>Ref Case</th><th>Low Demand</th><th>High NG Prices</th><th>More EE</th><th>Expanded RPS</th><th>Hydro from Quebec</th><th>Delay Nuke Retirement</th></tr>
<tr><td>8.2</td><td>8.0</td><td>8.6</td><td>7.4</td><td>7.5</td><td>7.7</td><td>7.0</td></tr>
<tr><td colspan="7">Uncertainties modeled as packages</td></tr>
<tr><td>Secular</td><td colspan="2">7.4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Policy</td><td></td><td></td><td colspan="2">7.0</td><td></td><td></td></tr>
<tr><td>Resource</td><td></td><td></td><td></td><td></td><td colspan="2">7.0</td></tr>
<tr><td>Sec+Pol</td><td colspan="4">5.2</td><td></td><td></td></tr>
<tr><td>Sec+Res</td><td colspan="2">5.2</td><td></td><td></td><td colspan="2">5.2</td></tr>
<tr><td>Pol+Res</td><td></td><td></td><td colspan="4">5.5</td></tr>
<tr><td>All</td><td colspan="6">4.0</td></tr>
</table>

5.2. Results without an Emissions Containment Reserve

In this and the following sections, we assume an annual reduction in the emissions cap over the next decade equal to 3.5 percent of the unadjusted 2020 emissions cap and examine market equilibria given potential unanticipated outcomes affecting allowance demand that are described in Table 1.

In Table 2, we focus on results for the last row in Table 1 because it has the most significant effect on the demand for allowances and illustrates the greatest changes in equilibrium outcomes. The first column of results in Table 2 indicates the model outcome in 2020 under the reference case with expected allowance demand and without an ECR that the electricity price is projected to be $143/MWh. Under the low allowance demand scenario without an ECR the electricity price falls to $140/MWh. The model anticipates reduced fossil generation in RGGI, but a larger share of that generation is achieved with coal, as indicated by the 29 percent increase in SO_2 emissions. In effect, the lower electricity demand and lower allowance price make room for more emissions intensive generation under the cap yielding a greater role for coal, even as nonemitting generation also increases due to assumptions about state-level support for renewables and increased hydro imports under this scenario. With no ECR in place, the same number of allowances are issued as under the reference case, but the reduction in emissions from covered sources in 2020 leads to more intertemporal banking. The lower allowance price leads to a reduction in the allowance value of over 50 percent, implying a decline in funding of various program-related activities, including support for energy efficiency.

Table 2. Simulation Model Results for 2020 under Three Alternative ECR Designs

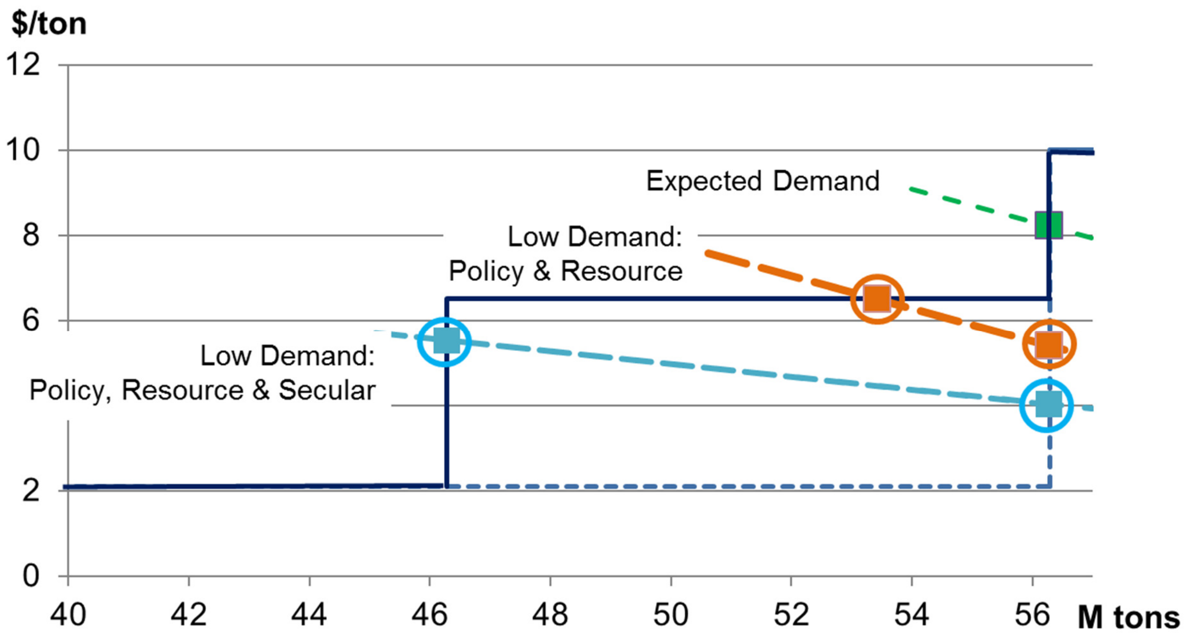
3.5% Annual Cap Reduction 2020 Results (2011 dollars)	**Reference Case**	**Low Allowance Demand**: Policy, Resource and Secular Unanticipated Outcomes			
	No ECR	No ECR	One Step ECR (10Mtons)	Three Step ECR (15 Mtons)	Ramp ECR (17.5Mtons)
Retail Electricity Price ($/MWh)	143	140	141	141	141
Fossil Generation (TWh)	143.5	112.1	101.7	107.6	106.4
Nonemitting Generation (TWh)	152.6	160.3	166.4	162.6	163.3
Allowance Price ($/ton CO_2)	8.2	4.0	5.3	5.0	5.0
RGGI Covered Emissions (Mtons)	72.3	70.1	62.5	66.6	65.8
SO_2 Emissions (Mtons)	10.4	13.4	11.8	12.8	12.7
Allowance Value (M$)	463	226	246	253	250
Incremental Leakage (%)	--	--	24%	26%	28%

5.3. Results with a Single Price Step

We explore three possible designs for the ECR. The first design is a single step ECR that would apply a minimum (reserve) price of $6.50/ton to ten million allowances (tons) per year beginning in 2020 and rising at 5% per year after that. Figure 6 illustrates the influence of the ECR under the expected level of allowance demand and two scenarios with reduced demand. The policy and resource scenario would yield an allowance price of $5.50 in 2020 in the absence of an ECR; however, the one-step ECR reduces the number of allowances entering the market and supports a market-clearing price equal to the ECR price step at $6.50.

The policy, resource and secular scenario represented in Table 2 leads to even lower allowance demand. The allowance price falls to $4 in the absence of the ECR, but with the ECR the allowance price increases to $5.30. Figure 6 illustrates that all of the ECR allowances are withheld from the market and the price falls below the ECR price level. Hence, one cannot suggest the ECR sets the price in the allowance market in the way that a minimum auction price might. The one-step ECR leads to a small recovery in the electricity price to $141/MWh, still below the level anticipated in the reference case. The constrained supply of allowances contributes to a reduction in fossil generation and a slight increase in nonemitting generation. Emissions of SO_2 are reduced by over half of the increase that resulted from low allowance demand in the absence of the ECR, but they are still 13 percent greater than in the reference case. Allowance value recovers by $20 million with this version of the ECR. Finally, we observe incremental leakage of 24 percent; e.g. the emissions reduction in RGGI associated with the ECR leads to a bounce back of emissions from uncovered sources in RGGI and in neighboring regions of 24 percent of that reduction.

Figure 6. One-Step ECR Outcome with Unanticipated Demand Changes



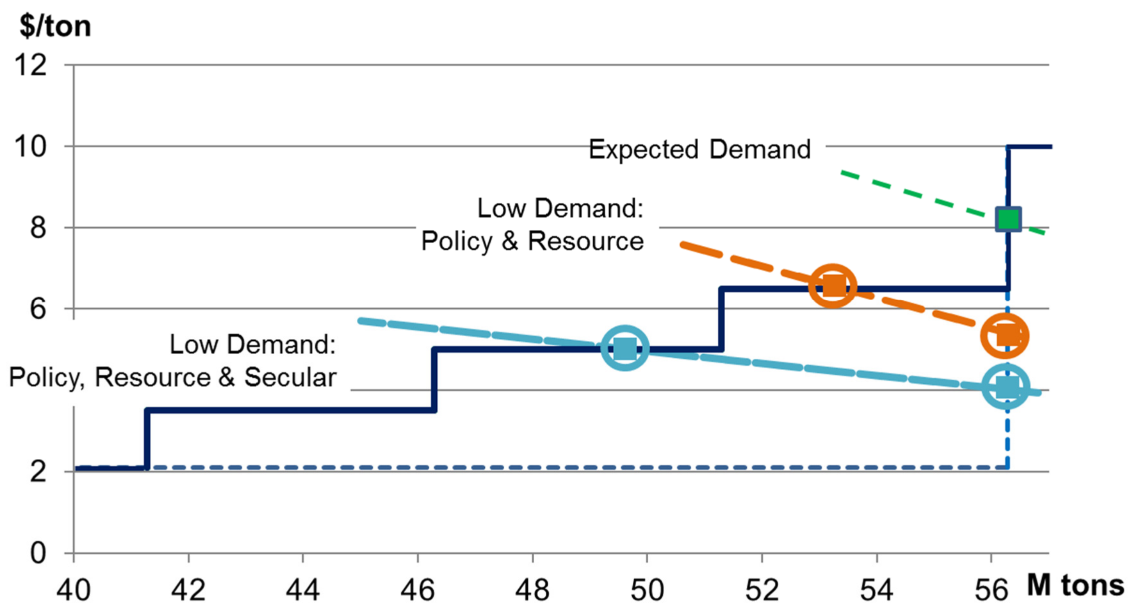
5.4. Results with Multiple Price Steps

In this section, we describe an ECR that has three steps implemented at $6.50, $5.00 and $3.50. Each step applies to 5 million tons in the auction. We note that this design is not necessarily more or less stringent than the one-step approach, but it can lead to different outcomes.

Figure 7 shows the same allowance demand scenarios as Figure 6. Under the policy and resource demand scenario the outcome is like the one-step scenario. That result occurs because we constructed the top step of the three-step ECR at the price level of the one-step scenario, and the auction clearing price lands on this portion of the ECR. However, the result is different with still lower allowance demand under the policy, resource and secular scenario. More allowances are issued under the three-step ECR, and the auction clearing price is lower, than under the one-step ECR.

The three-step ECR results in virtually no change in electricity price compared to the one-step ECR. Fossil generation recovers about halfway, compared to the one-step ECR, reflecting the lower allowance price, and RGGI covered emissions are slightly higher in 2020. Emissions of SO_2 increase almost to the same level as in the absence of the ECR, allowance value grows slightly, and leakage is roughly the same as in the one-step ECR.

Figure 7. Three-Step ECR Outcomes with Unanticipated Demand Changes



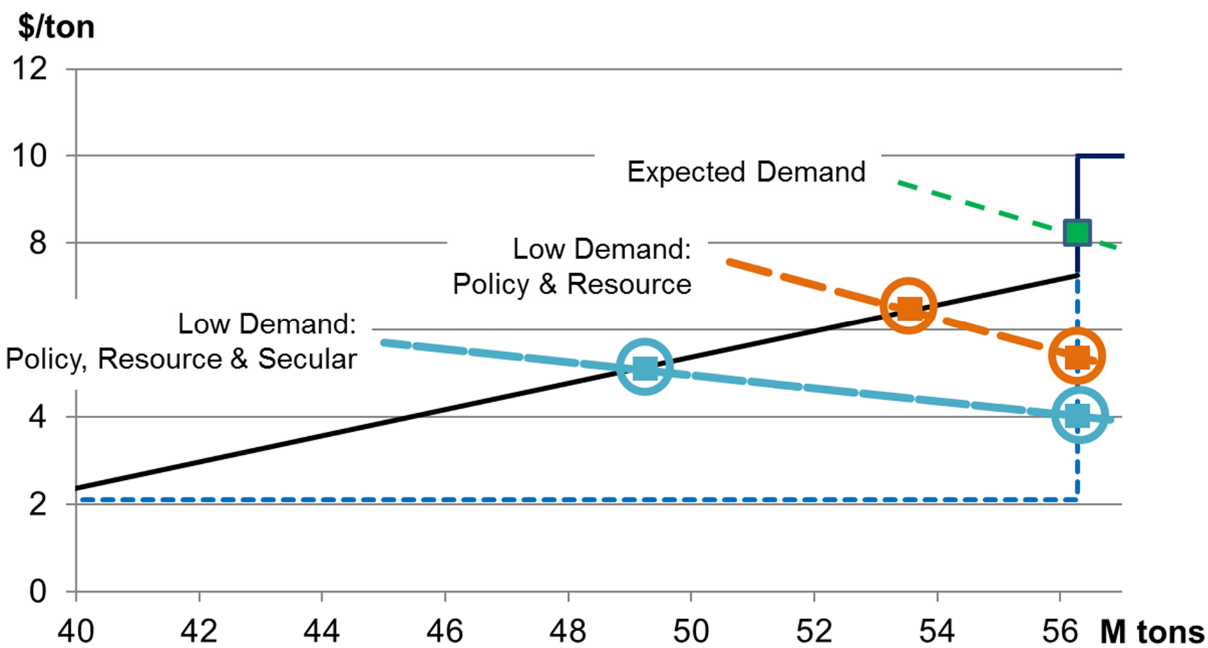
5.5. Results with an Allowance Supply Ramp

The third design we study in detail is a continuous schedule, or ramp, that begins at $6.50, the same value as the other two ECR designs we have discussed. The ramp declines linearly over 17.5 million tons until it meets the price floor at roughly 40 million tons. Figure 8 illustrates that virtually the same outcome is achieved under the policy and resource demand scenario as under the other two ECR designs. This outcome occurs by construction and is presented for illustrative purposes. However, with still lower allowance demand under the policy, resource and secular scenario the outcome varies from the other scenarios.

Slightly different levels of fossil and nonemitting generation result under the ramp, compared to the three-step ECR. The ramp achieves almost the same allowance price as the three-step ECR (the difference is obscured due to rounding), consequently, the ramp ECR has similar outcomes for emissions, allowance value and leakage.

It is important to observe that any one of these ECR designs is not necessarily more stringent than the other. However, they have different effects under various profiles for allowance demand, and the comparison illustrates how the market equilibrium is achieved.

Figure 8. Ramp ECR Outcomes with Unanticipated Demand Changes



5.6 Summary of Simulation Results and Sharing of Risks and Benefits

The results described above reveal that an ECR in RGGI yields a sharing of the benefits from reduced compliance costs when allowance prices are lower than expected. The ECR would abbreviate the price decline by reducing the supply of emissions allowances thereby creating environmental benefits in addition to economic benefits. While this modeling exercise has focused on outcomes that lead to lower than expected allowance demand, a similar sharing of risks and benefits between economic and environmental outcomes would also occur in a situation where demand for allowances is higher than anticipated and the CCR is triggered thereby raising the supply of allowances and alleviating some of the costs of a regulation.

We examined over two dozen scenarios that incorporate various unanticipated outcomes that reduce the demand for emissions allowances and the allowance price including those described in Table 1 and several other exploratory scenarios. Across these scenarios in the RGGI context we found that introducing an ECR has virtually no effect on electricity prices. We found it produces small and predictable changes in the mix of generation resources. For example, when the ECR is triggered and allowances prices rise, generation by emissions-intensive resources declines. The impact on the size of the bank is unpredictable. While changes in allowance demand are unanticipated by the policy maker, they are anticipated in the model, which minimizes the present value of costs. Banking behavior in the model responds to the timing of "unanticipated outcomes." For example, if the influences that exert downward pressure on electricity demand accumulate over time, then the ECR will be more relevant later in the decade and future reduction in allowance demand will be anticipated in the model. This effect is the prevailing trend in our scenarios and therefore there is typically more banking with an ECR. However, the opposite occurs in the laboratory experiments, which are discussed below.

In scenarios where the ECR plays its most influential role, for example as reported in Table 2, we find SO_2 emissions decline by up to 9 percent compared to no ECR, as the use of coal responds negatively to the increase in allowance prices under the ECR. Allowance value increases by up to 20 percent compared to the absence of the ECR as allowance price increases more than offset reductions in the quantity of allowances sold at auction. This increase enables increases in program related spending in RGGI. We also observe incremental leakage from the ECR hovers around 30 percent, meaning in effect that the cost of a ton of incremental emissions reductions achieved due to the ECR is 30 percent higher than is reflected by the change in the allowance price, or equivalently that RGGI has to reduce emissions by 1.3 tons in order to achieve 1 ton of emissions reduction from a global perspective.

The unexpected decline in the demand for allowances have various probabilities of being observed. From an ex-ante perspective informed by modeling, we conjecture a probability distribution of possible allowance prices both above and below expectations and that outcomes closer to the anticipated allowance prices are more likely than lower prices, at least in the near term. In this context, the benefits of a small deviation from the anticipated allowance price that does not cause the price to fall to an ECR price step accrue entirely to economic interests. A larger deviation that leads price to fall to an ECR price step would accrue to both economic and environmental interests. If the demand for allowances falls enough that all ECR allowances are withheld from auction, then the allowance price would fall below the lowest ECR price, leading to further gains for economic interests, until the price reaches the price floor. A CCR that introduces additional allowances when prices are greater than expected would have a converse effect, i.e. compliance costs increase initially as prices rise, but when the CCR price step is achieved additional allowances enable additional emissions to occur, and so on. A price responsive supply schedule can be envisioned to combine the ECR and CCR.

The structure of the ECR affects the pattern of sharing from low price realizations. With more price steps the benefits of low allowance demand are shared more evenly. Economic interests would get the first piece, environment the second, and so on alternating until the price reaches the price floor. Ultimately, the most equitable sharing would come from a continuous ECR, under which any decline in allowance price leads to fewer allowances entering the market.

6. Exploring the Emissions Containment Reserve in a Behavioral Context

The second approach to investigating the role of an ECR considers the way that individuals and markets respond. We pursue this using experiments to examine how the implementation of an ECR might affect trader behavior in the stylized setting of the economics laboratory where college students participate as research subjects in a simulated market with carefully structured incentives and real monetary pay offs. Experiments have been used previously to explore the likely effects of market designs in all of the key emission markets implemented to date, including RGGI, the SO_2 allowance trading program, the eastern US NO_x market, the EU ETS, and the California CO_2 cap-and-trade program. In the case before us, we are interested in measuring the effect of adding an ECR to a simulated market designed to mimic essential features of the current RGGI market.

6.1. Making It Look Like RGGI

An experiment comprises a set of treatments, where we vary one feature of the market at a time to observe the differences in outcomes that arise from changing just the one market feature. We explore each treatment with a series of laboratory sessions with human subjects to test for differences in outcomes that arise from the specific change to market design under examination.

We examine three treatments, one representing no ECR as a base case, and two others representing the addition of two forms of an ECR. These forms are a single-step ECR $8 for 16 allowances (25 percent of the initial cap) and, as an alternative, a linear ramp ECR that declines smoothly from the ECR trigger price to the auction reserve price, which is assumed to be $5 per ton. Each of these three treatments - baseline, step and linear - has precisely the same structure except for the introduction of an ECR and the way it is characterized.

Our laboratory setup presents subjects with a simplified version of the RGGI market, where the focus of the simulation is on essential features that drive trader behavior. Bidders can only acquire allowances in the auction; there is no spot market. However, the bidders interact through the determination of the equilibrium allowance price, which in turn affects the possibility that the ECR will be triggered. Each experiment includes 12 participants and each participant controls four “capacity units”, each of which produces one unit of output per period.

Half of the participants own low emitting units, which require one permit per unit of output, while half own high emitting units requiring 2 permits per unit of output.

Banking is unlimited. The price of electricity output varies between $30 and $40 per MWh with a probability of 50% each and the cost of production varies uniformly on [$10, $28] per MWh for low emitting "gas" units and on [$1, $28] for high emitters (coal). Each session has 30 periods with a cap that is declining over time from an initial value of 66 units to a final value of 37 units. The tightening of the cap gives participants the incentive to anticipate future increased scarcity and smooth the availability of allowances over time by banking in early periods for use in later periods. Previous experiments have shown participants to be very adept at smoothing the supply of allowances over time (Holt and Shobe 2016). What this implies for our sessions is that the price in early sessions will provide a good signal about the long-range tightness of the cap. If there were no smoothing, we would expect to see the price rise as the cap falls, but with effective smoothing, the price in early periods will be very similar to the price in later periods.[6]

Thus, if we observe a high allowance price, we can infer a relatively tight long-run cap. Alternatively, a low allowance price implies a relatively slack cap. In an allowance market like RGGI's, with a cost containment reserve, a tight cap would have a relatively high probability of triggering a release of allowances from the reserve. At the other extreme, a very slack cap would have a relatively high probability of having the auction close at the reserve price with some allowances unsold.Market participants know about the presence of the ECR and the reserve price and develop their bidding strategies that reflect expectations about future scarcity.

The purpose of the proposed ECR is to take account of the information that a chronically low price provides to the RGGI states. It is a signal that participants do not see the future scarcity of allowances rising so much that the declining cap cannot be managed, and that future compliance costs can be held down through banking.

Given the ability of market participants to consider future scarcity in today's actions, the presence of the ECR and the likelihood that it will be triggered and will reduce the long-term supply of allowances should have a predictable effect: it should raise today's price relative to a market without the ECR. The ECR could also change the incentive to bank allowances for the future. In theory, early banking could go either up or down in response to the presence of the ECR. If participants anticipate the future triggering of the ECR would make banked allowances more valuable in the future, then participants will choose to bank additional allowances. On the

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[6] In the experiments we are assuming a zero discount rate for simplicity. This does not change the key results.

other hand, participants may see the ECR as lowering the total supply of allowances, so banking could conceivably fall and this outcome may appear intuitively more likely and, in fact, it is the outcome we observe in our preliminary experimental sessions.

Regardless of the pattern of banking, prices should be higher in a market with an ECR relative to a market without an ECR and this effect should occur even in sessions where the ECR is not actually triggered. Market participants will view the triggering of the ECR as a possible future outcome and will adjust their behavior accordingly. The presence of the ECR actually makes it somewhat less likely that the price level that would trigger the ECR will ever be observed.

6.2. Results from Preliminary Rounds

Preliminary results reported here are based on two sessions in each of our three treatments: no ECR, step ECR and linear ECR. The key results are presented in Figures 9 through 11. Figure 9 clearly shows a pattern of higher average allowance prices for sessions with an ECR than for sessions without an ECR. This is true for both types of ECR and prices are higher than the no ECR case in almost all periods.

In our sessions, the increased scarcity of allowances with either type of ECR reduces the amount of banking relative to the no ECR treatment. Nonetheless, while the ECR does result in a smaller number of allowances sold on average, the rise in price makes up for the reduced sales. There do not appear to be big differences in revenues across the two ECR treatments, although the linear ECR results in somewhat higher revenue; more sessions are needed to know if this difference is statistically significant.

Figure 9. Average Auction Price by Treatment by Round

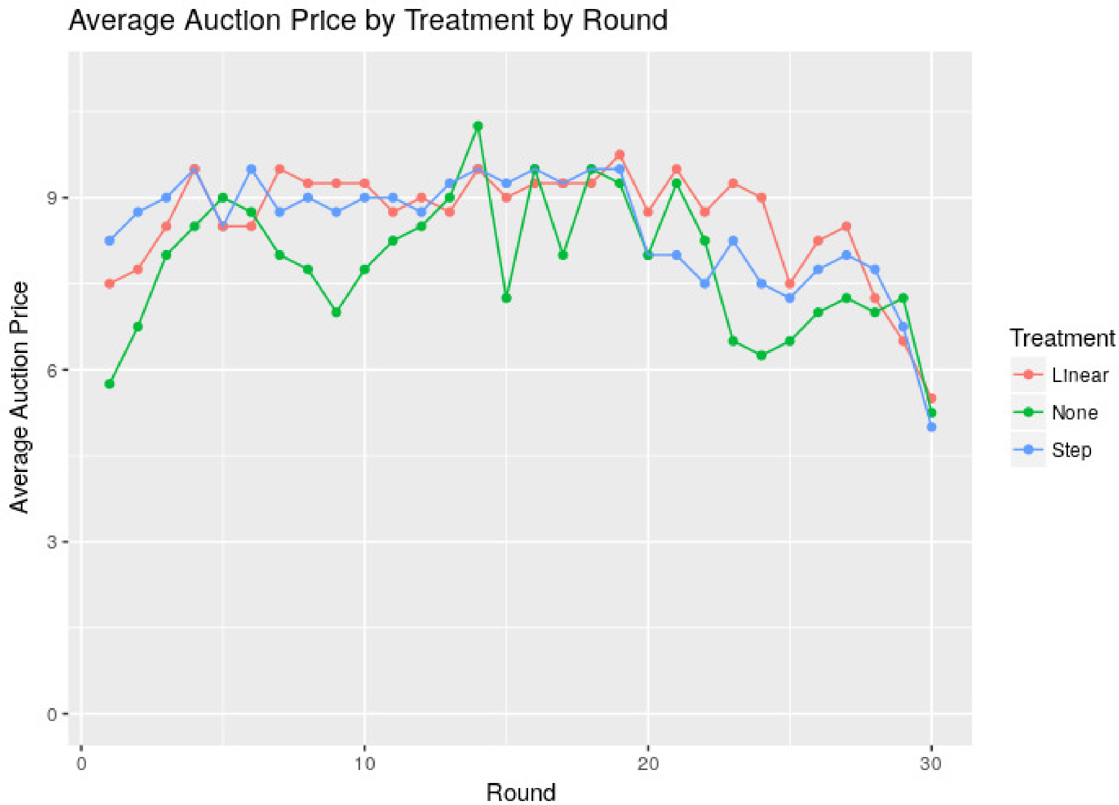


Figure 10. Total Banked Allowances by Treatment by Round

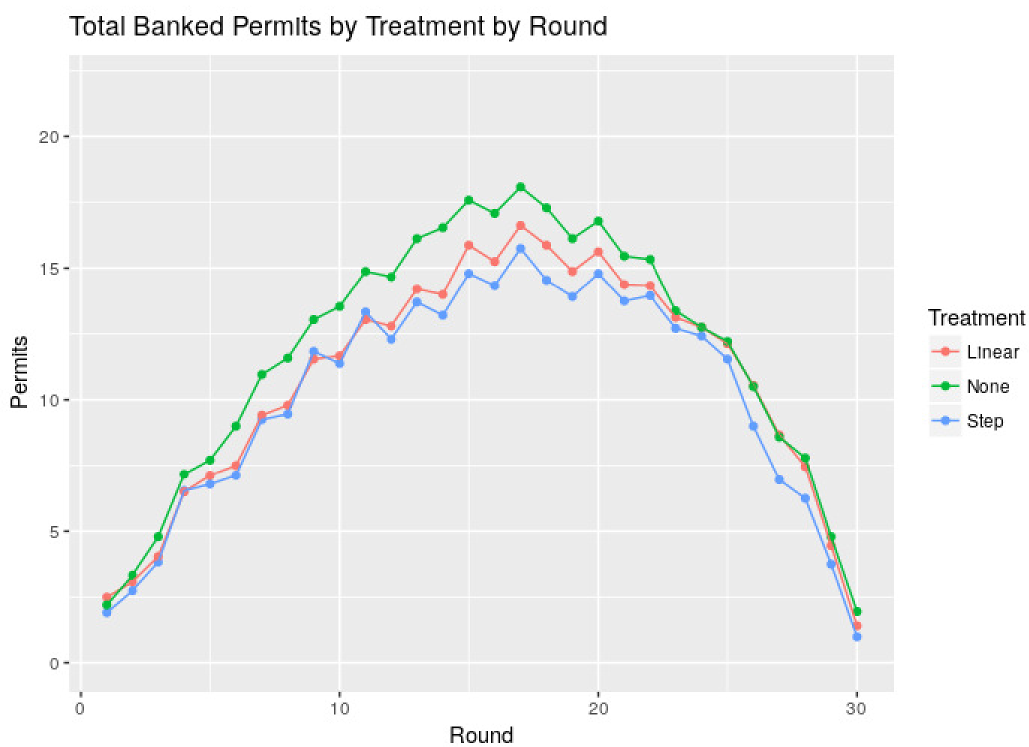
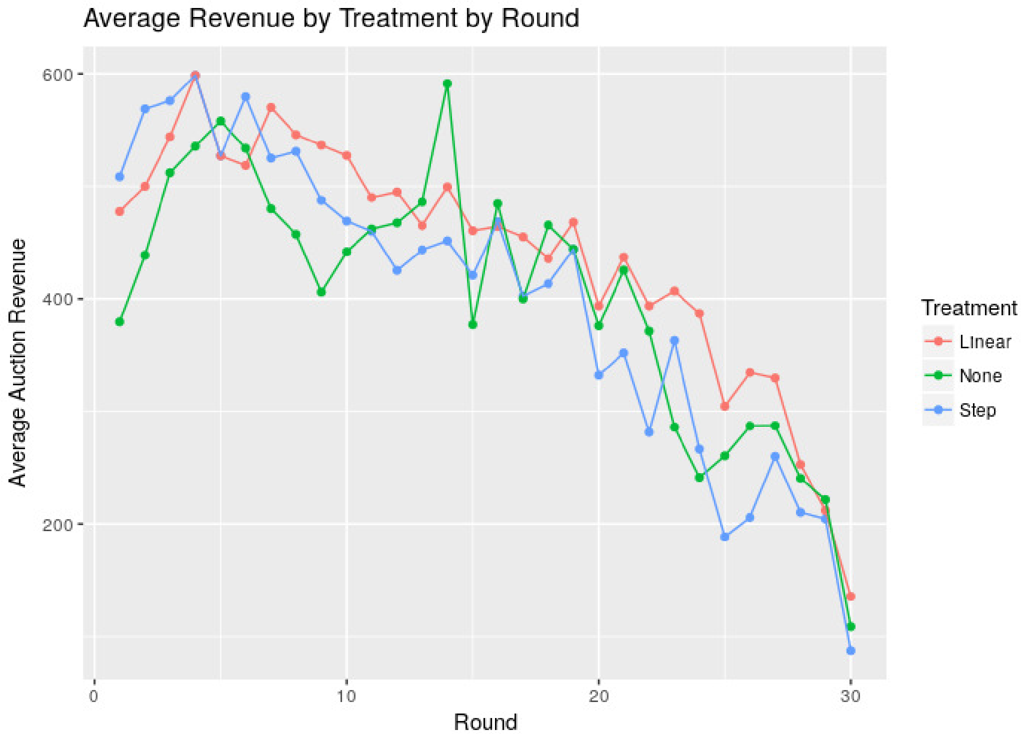


Figure 11. Average Revenue by Treatment by Round



7. Implementation of an Price Responsive Emissions Supply Schedule

Implementation of a price responsive emissions supply schedule is a small modification to the conventional emissions trading program. It involves decisions on five design features all of which were relevant as RGGI designed its approach to its ECR.

<u>Number of intermediate supply curve steps</u>: The decision about how many steps to include, or whether to use a continuous supply schedule, is informed by considerations of program simplicity. Because experiences with emissions trading have typically involved a perfectly inelastic supply of allowances with no price step, a single-step supply curve (potentially in addition to the price floor and high end CCR) may appear to be a smaller departure from the current program design. However, conceptually it is no simpler and in some ways more abrupt in its impact on the market equilibrium than a multi-step or continuous supply schedule, and hence it may be more difficult for market participants to anticipate outcomes in the face of uncertainty with a single intermediate step.

The substantive consideration in choosing the number of steps is the sharing of the benefits and risks of unanticipated levels of demand that would be realized if compliance costs and allowance prices differ from expectations. The sharing from a multi-step or continuous supply schedule is more even and continuous than from a one-intermediate-step supply schedule.

As noted, the multi-step and continuous approaches make it less likely that any particular price step ends up being the price that clears the allowance market.

Level of the supply schedule price step(s): The supply schedule price step(s) or the slope of the price ramp would be set between the minimum and maximum prices in the trading program and enforced through reserve prices in auctions. This process involves the identification of three values. One is the quantity of allowances under the cap that maps into the expected allowance market price. Second, if relevant, is the price floor (and cost containment reserve if offered in addition to the supply schedule), and third is the intermediate price step(s). Because of the uncertain nature of the underlying problem these are simultaneous considerations. Trading programs could approach this problem in a hierarchical manner, deciding first on the fundamental parameters of an anticipated price and price floor before setting the intermediate price step that would provide an incremental adjustment in the supply of allowances should demand for allowances end up deviating from expectations.

Price step quantities: If discrete step(s) are introduced, each will have to apply to a specified quantity of allowances that would not enter the market at prices below the respective price steps. A continuous function would not have quantities identified with each step but it would require identifying the quantity of allowances that would be brought into the price ramp.

Change in the price steps over time: With banking under the program, the Hotelling rule posits that the price of allowances will rise steadily at the real intertemporal opportunity cost of capital and many economic models enforce such a price path over time. In light of insights from economic theory, a policy maker might choose to stipulate that the price step also rises at this rate. However, the opportunity cost of capital is itself an uncertain variable and the specified time path for the levels of the price steps will affect its relevance as that uncertainty is resolved. More importantly, the Hotelling rule has generally not prevailed in air pollution allowance trading markets or in other commodity markets. The simple version of the Hotelling rule does not account for the many exogenous changes in technology, economic conditions, other policies and industry choices in the future that deviate from expectations at the time the cap-and-trade policy is established. Also, it assumes that the cap-and-trade program will remain in effect, but the existence of the program is itself uncertain. Given, these qualifications, an alternative to basing the rate of growth for price steps on the model-identified price path may be appropriate. If the price step is specified to grow at the same rate as the model-identified price path and the realized allowance price grows at a slower rate, then the price step would become more influential over time. Similar considerations apply to the rate at which the price floor and cost containment reserve increase over time.

Disposition of unsold allowances: When an allowance auction clears at a price at or below the level of a price step, there will be a smaller quantity of allowances sold than is available in the auction. There are several alternatives for how to dispose of allowances that are not sold. One is to roll the allowances forward to future auctions. A second is to use them to undergird the CCR, so that they would only re-enter the market if the auction cleared at very high prices. These alternatives, however, undermine the function of the price schedule approach to provide sharing between risks and benefits when compliance costs are low, which would be accomplished if the allowances were permanently retired. Conversely, if a price responsive supply curve led to the introduction of additional allowances to the market because allowance prices were higher than expected, regulators would have to decide where those allowances come from. In California, for example, revenues from the sale of these allowances would be directed to purchase emissions reductions from outside the program.

8. Conclusion

Economic advice for climate policy derives from identification of a first-best result in solving a global environmental problem. However, climate policy is taking shape at the level of individual nations and even sub-national jurisdictions. Nonetheless economic ideas have had an important influence in the emergence of regional cap-and-trade programs. These programs are designed around the concept of a perfectly inelastic supply of emissions allowances, which might be first best from a global perspective, but is not when implemented in a non-cooperative context. In practice these programs have added auction price floors and cost containment reserves; nonetheless, over a large range of potential allowance market equilibria, the quantity of allowances in existing trading programs is fixed. This approach has several disadvantages, including highly variable allowance prices and auction revenue, and it undermines the environmental effectiveness of additional voluntary actions taken by individuals and of other types of policies adopted by subsidiary jurisdictions within the emissions-capped regions. This limitation on environmental effectiveness can pose a major obstacle to further implementation of economic approaches and to further progress in reducing greenhouse gas emissions.

This paper recognizes that in practice existing cap-and-trade programs have begun to introduce price floors and cost containment reserves that are departures from perfectly inelastic allowance supply, although between these price points supply is inelastic. However, this evolution has begun to change the form of emissions trading programs with the addition of the emissions containment reserve in RGGI, which introduces a price step above the price floor but below the expected price. We identify several advantages of this design within a simulation model of the RGGI region and in laboratory experiments, including less price and revenue variability and greater incentives for voluntary additional actions to reduce emissions. The departure from conventional practice is a significant one, overcoming the difficult choice between price versus quantity instruments that has characterized over forty years of economic debate, and moving toward a design for environmental markets that more closely resembles that of other commodities. Importantly, we recognize the supply of emissions allowances as instructions from the regulator to the market, reflecting the outcome of domestic regulatory negotiations. These instructions reveal a willingness to pay for emissions reductions, and as prices fall or rise, supply falls or rises as well, as in other markets. We describe the set of decisions about design features that must be made in order to implement this approach.

As part of their 2016 Program Review, the RGGI states adopted an emissions containment reserve that sets a minimum price on a portion of the allowances available for sale at each RGGI allowance auction above the auction reserve price and below the price that is expected to clear the auctions. If RGGI compliance costs are lower than anticipated (i.e., low allowance prices clear the auctions), then the reserve would be triggered and some allowances would not enter the market. Fewer allowances in the market supports the allowance price, and implies fewer emissions within RGGI and gains for the environment.

RGGI's interest in considering price response allowance supply arises from the observation that the costs of compliance with cap-and-trade programs for airborne emissions worldwide frequently tend to be considerably lower than ex-ante expectations. This outcome has certainly been observed in RGGI as 11 of the 36 allowance auctions have cleared at the reserve price and with others clearing just above the reserve price. In the absence of the reform, low demand for emissions allowances leads to a reduction in allowance prices. Unless demand is so low that prices are at the auction reserve price, low demand and low prices are an economic benefit with no coincident environmental benefit. This result is a manifestation of what we call the "waterbed effect." An emissions reduction effort such as investment in energy efficiency undertaken by any entity in a RGGI state will simply make more allowances available to other RGGI entities and no additional emissions reduction is realized, at least until a potential cap adjustment as part of a subsequent program review. The waterbed effect undermines the incentive for environmentally motivated cities, states, companies, and individuals to take actions to reduce emissions associated with electricity consumption as any such actions may yield no climate benefit.

Some observers have expressed a concern that varying from an inelastic allowance supply might transform the quantity based program into one that determines the price in the allowance market. However, if the market price falls to the reserve price step then some allowances do not enter the market, which in turn has an effect on allowance prices, the mechanism does not determine the price. Our simulation modeling indicates that the allowance price may end up below the ECR price step or below multiple steps. Any allowance price at or above the auction reserve price (price floor) may clear the market and the ECR merely affects the quantity of allowances that enter.

A price responsive supply curve introduces new considerations with respect to the possibility of linking with other allowance trading programs, but they are strongly analogous to the considerations that a program such as RGGI already would take into account because of its price floor. Under the ECR, as under a price floor, if allowances are not sold by the RGGI states the allowance price will be supported. Our modeling indicates that this leads to a net increase in the revenue from the auction, but the benefits accrue even more strongly to the linked jurisdiction(s) that is able to sell all of its allowances at the higher price enabled by the ECR. Negotiation about linking may want to take this distribution of benefits into consideration.

RGGI has been seminal as a market-based regulation of CO_2 emissions in the United States and across the globe for introducing features that have broad appeal. RGGI was the first program to sell almost all of the emissions allowances by auction and, as such, the first to implement an auction reserve price. These features of RGGI have found their way into California’s cap-and-trade program, in Quebec (which is now linked with California), and in Ontario. The emissions containment reserve appears to be another RGGI innovation that would better align incentives for individual actors in the region and help to better integrate cap and trade with companion efforts in cities and states and by private actors to promote clean energy and reduce CO_2 emissions. In a world where these companion programs will continue to exist and play an important role, the price responsive supply curve could serve as a model for other greenhouse gas cap-and-trade programs.

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WORKING PAPER

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Quantities with Prices

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RESOURCES FOR THE FUTURE

Quantities with Prices

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Abstract

First-best environmental policy in the presence of uncertainty is often posed as a choice of price versus quantity instruments. In practice, climate policies are incremental and multi-faceted, combining economic and regulatory approaches, and determined with limited geographic scope that does not balance global benefits and costs. Quantity emissions targets are typically preferred, designed on principles derived from the first-best framework that apply imperfectly to the partial equilibrium policy setting. This paper recognizes and evaluates the emergence of price responsive emissions allowance supply schedules in existing trading programs. We use simulation modeling and laboratory experiments to explore different forms of a supply schedule, with application to the Regional Greenhouse Gas Initiative trading program. We find that a price responsive supply schedule usefully shares the risks and benefits of unexpected outcomes with respect to emissions control costs between economic and environmental interests, and preserves incentives for companion technology and energy policies.

Key Words: cap and trade, climate policy, greenhouse gas, climate change, electricity

JEL Classification Numbers: Q48, Q54, Q58

Contents

Quantities with Prices

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1. Introduction.

Two central principles of environmental economics are (1) that economically efficient policies to limit harmful emissions should be designed in a way that equates the marginal benefits of limiting emissions to the marginal costs of doing so and (2) that policy should be set at a geographic scale that captures all relevant contributors to the problem of concern (Oates 1999). In the case of global climate change, this first-best set of principles suggests that an optimal greenhouse gas policy would be global in design. In the early years of global climate negotiations coordinated by the United Nations such an approach was embraced by the majority of nations in the Conference of Parties and this support was reflected in the nearly global cap-and-trade system in the 1995 Kyoto Protocol. However, in practice it proved impossible to achieve the consensus necessary to implement such program. Instead, at the UNFCCC meeting in 2016, the countries of the world opted for a different approach in the Paris Accords. This new climate agreement codifies a country by country approach under which each nation makes a pledge establishing national emissions reduction goals and declaring policies for reaching those goals. In some parts of the world, including the United States and Canada, the decentralized approach to climate policy extends to the subnational level in many cities, states and provinces, with cap-and-trade programs in the Western Climate Initiative including California, Quebec and Ontario, and in the Regional Greenhouse Gas Initiative involving a group of northeast states, as well as a carbon tax in British Columbia.

A third lesson from environmental economics is that identifying a globally optimal policy for limiting pollution requires the choice of a control variable: either prices or quantities

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(Weitzman 1974). Most, but not all, of the evidence favors a price based approach, particularly in the case of stock pollutant with relatively flat marginal benefits from reduced emissions (Hoel and Karp 2001, Newell and Pizer 2003). Nonetheless, most of the national and subnational programs have adopted a cap-and-trade approach and, while the level of the emissions cap determines the marginal cost of reductions, that level of regulatory stringency has not been calibrated to global economic measures of the marginal damage from incremental emissions. Instead emissions caps are determined as part of scientifically informed regulatory and political negotiations that occur primarily within the jurisdiction, not between jurisdictions. Hence, the emissions allowance quotas in existing programs do not align with the marginal social cost of carbon emissions. Importantly, the quota is typically a fixed quantity of allowable emissions determined through this negotiation, a design that derives from first-best theory, but does not necessarily apply in a partial equilibrium policy context. Nonetheless, the basic principle of cost effectiveness is preserved in the allowance market equilibrium that balances marginal benefits (the allowance supply schedule) with marginal costs of emissions reductions (the demand for emissions allowances).

While this market based approach supports cost effective outcomes, the typically perfectly inelastic supply (fixed quantity) of emissions allowances in these markets at least in periods between adjustments to the program offers a limited ability for the market to respond to new information including lower or higher than expected emissions control costs and demand for allowances, as well as the resolution of uncertainty over time. In most commodity markets, supply curves have a less than infinite slope; as the amount of the commodity that enters the market decreases (increases) with decreases (increases) in the market price. If demand falls, thereby decreasing market prices, less of the good is brought to market which tends to buffer those price decreases; however, in emissions allowance markets, typically only the allowance price can adjust to new information. In some allowance markets concerns about high prices have led to the establishment of absolute price caps or, more commonly, cost containment reserves that introduce a limited quantity of additional allowances at specified price levels to buffer unexpected price spikes. Many programs that use auctions to distribute emissions allowances initially also have a price floor below which no allowances will be sold. But in these markets, supply curves remain perfectly inelastic between these two price points.

The standard design for emissions markets is derived from the seminal formulation of a global optimization problem with the choice of the control variable to be either prices or quantities, with some authors (described below) suggesting hybrids and adjustment mechanisms. The innovation in allowance markets that we observe and characterize here is the introduction of a price responsive supply curve to allowance markets replacing a perfectly inelastic supply function. Such a supply schedule embodies instructions from policy makers to the market and allows the quantity of allowances supplied and market equilibrium to change with new realizations about program costs resulting from a range of factors. With a price responsive supply schedule, which we describe simply as quantities with prices, the market equilibrium will shift along the supply schedule resulting in a change in price and quantity, as in a standard commodity market.

The perfectly inelastic supply of emissions allowances has several disadvantages for regulators. One is that revenue that can be raised from the auction of emissions allowances is variable; as the price changes the revenue changes in direct proportion. Major carbon emissions trading programs include provisions for reinvesting auction revenues, but planning for such investments is difficult when revenues are highly variable, and these variations have sometimes been described as signals of program failure. A second disadvantage is that all the impact of price fluctuations accrues to the compliance side of the policy ledger, by reducing costs when prices fall and increasing costs when they rise, without any change in the environmental outcome. In practice, the much more prevalent outcome has been for prices to fall below expected levels, in part due to the role of additional measures implemented by other jurisdictions (Burtraw et al. 2018), with the benefits of the price drop accruing strictly to the economy. Hence, a third and related disadvantage from the regulator's perspective is that, because only prices change in response to changing demand for allowances and emissions do not change, the inelastic supply undermines the incentive for individuals and subsidiary jurisdictions within an emissions-capped region to take additional actions to reduce emissions (Goulder and Stavins 2011). However, from a regulator's perspective, if changes in the baseline and especially voluntary action leads to downward pressure on allowance prices, one might expect that action to result in reduced emissions. Indeed, if emission reductions are less expensive than anticipated, one might expect economic behavior to lead to buying more of them, but until very recently this feature has been missing from existing emissions trading programs, rendering them less desirable in the minds of some regulators and environmental advocates.

We envision the policy-determined supply schedule in an emissions trading program to embody instructions to the market from policy makers in the face of uncertainty about costs, innovation, other policies in one's own jurisdiction and policies in other jurisdictions that also will affect these outcomes and the market equilibrium. In this paper we describe a fundamental evolution that is taking hold in emissions trading programs, the introduction of a price-responsive supply of emissions allowances. This approach allows for the general setting in which allowance demand may differ from expectations in either direction (Borenstein et al. 2016).

In section 2 we review the literature, much of which has anticipated adjustments to either a price or a quantity approach to make it more like the other, but for the most part has started with one or the other as a basic model, in contrast to most markets where price and quantity are mutually determined with the supply of a commodity. In Section 3, we compare the conventional vertical supply curve for emissions allowances with a step-wise supply schedule and a continuous schedule. In Section 4 we describe this innovation in the specific context of the Regional Greenhouse Gas Initiative, which recently adopted this approach in what it describes as an "emissions containment reserve." In Section 5, we report simulation modeling of outcomes concerning various formulations for a supply schedule in that context. We quantify the sharing of benefits from a decline in allowance demand between economic and environmental outcomes and observe that the price responsive supply curve helps preserve emissions reductions that are achieved by companion policies enacted by individual jurisdictions within the capped region. We find that auction revenue is expanded under a price-responsive supply curve, even though fewer allowances are sold, making greater revenue available for program-related spending.

In Section 6 we supplement the simulation modeling with laboratory experiments. We find the emissions containment reserve is easy for market participants to understand and does not interfere with the performance of the allowance auction. We also observe that the interaction between demand and supply helps reduce price volatility. In Section 7 we analyze issues associated with the implementation of an elastic supply schedule, before concluding.

2. Literature

Climate science suggests that the emissions reductions necessary to limit the degree of global warming in a meaningful way are substantial and achieving them would require a large transformation of the energy sector and a major shift away from fossil fuels expected to unfold over time. The policy pathway toward this goal is usually manifest in a cap and trade program with a cap on emissions that declines over time. The costs of meeting those caps are highly uncertain, particularly further into the future as policy goals become more ambitious. The early literature dealing with uncertainty in the design of climate policy focuses on situations where marginal costs of achieving emissions targets might turn out to be higher than expected and developing policy features to offer some relief should policy goals prove expensive to attain. Most of these proposals involve a combination of quantity and price mechanisms first discussed by Roberts and Spence (1976). Pizer (2002) is one of the first to consider the combination of policies in the climate regulatory context and shows that combining a price and quantity is more efficient than a price based mechanism alone, including when the policy goals are not set optimally. Aldy and Pizer (2009) discuss various options that have been included in climate policy proposals discussed in the US Congress and elsewhere including a safety valve cap on the price of emissions allowances at which additional allowances enter the markets, a circuit breaker that would stall the rate of decline of an emissions cap if allowance price hits a specified level and establishing an independent board to manage the supply of allowances to keep prices within an acceptable range (Murray et al. 2009). Similar mechanisms are envisioned with respect to how an emissions fee could be adjusted to achieve an emissions goal (Newell et al. 2005, Aldy et al. 2017). Virtually all discussions start from one of the two conceptual approaches, quotas or fees, and explore modifications that make one look like the other or, potentially, offer a hybrid of the two approaches. This construction differs, however, from virtually every commodity market in which the supply of the commodity varies with the equilibrium price obtained in the market.

One cost-related concern is that prices might spike due to short-run factors such as weather or disruptions in fuel supply and this spike could have deleterious effects on the economy. Cap and trade programs typically include features that can help to mitigate the likelihood of price spikes. One approach is allowing temporal banking and borrowing of allowances. The early literature on banking focused on smoothing temporal fluctuations to minimize the present discounted value of complying with regulatory goals over time and did not discuss the issue of uncertainty (Cronshaw and Kruse 1996, Rubin 1996, Kling and Rubin 1997). More recently, Fell et al. (2012c) consider a situation with uncertainty about compliance costs and show that cap and trade with banking can replicate the efficiency of a price based policy in the climate context. Recognizing that policies are likely to be updated over time and that allowance banking enables intertemporal arbitrage, Pizer and Prest (2016) show that a quantity based policy can be superior to a price based one given that arbitrage over time is not possible with a price based policy. Offsets from outside the regulated sector (or associated with mitigation of emissions of non-CO_2 gasses) are another mechanism that can help to reduce the costs of compliance and the likelihood of short term prices spikes, although the supply of offsets is also uncertain and may be correlated with other compliance costs, which could amplify price fluctuations (Fell et al. 2012b).

Throughout most of the literature and all that we reference above, the economic issue is described as a design problem from a system (global) perspective. However, the Paris accord places hope for progress on international climate policy on bottom-up, loosely coordinated actions of independent jurisdictions, wherein decision makers have even less information about benefits and costs of mitigation and the mitigation efforts that will be taken by other jurisdictions, but where they can be expected to have some success in coordinating actions (Barrett 2016). As climate policies have evolved in fairly small geographic markets, aligning policies and program designs can be the precondition for greater linking across programs

(Burtraw et al. 2013). Linking may help mitigate price volatility through broadening markets, mitigate concerns about competitiveness between jurisdictions (Jaffee et al. 2009), and enable greater environmental ambition by keeping costs low (Bodansky et al. 2015) especially where independent programs yield different stand-alone allowance prices (Flachsland et al. 2009).

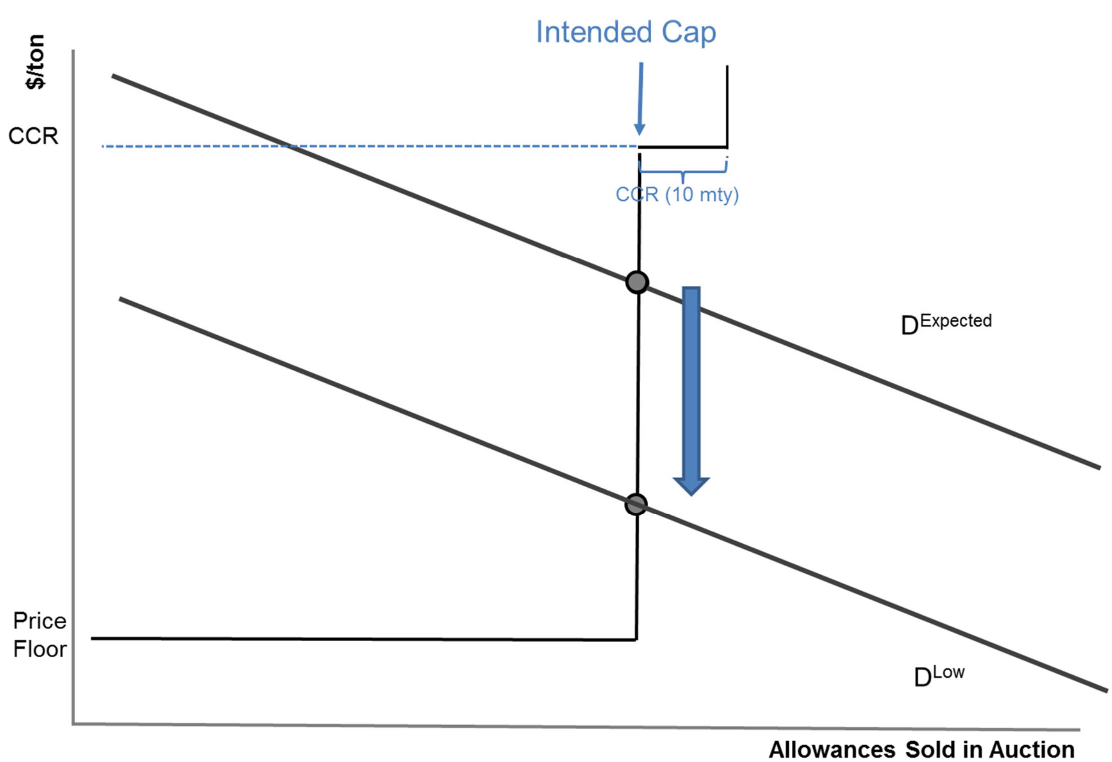
While the literature is overwhelmingly about shielding markets from high cost shocks, experience in virtually every cap and trade market suggests that lower than expected prices are a more likely outcome. These low price outcomes result primarily from lower than expected demand for allowances. One mechanism that has been suggested for dealing with this approach is a price collar that incorporates both a floor on allowance prices and a ceiling. Burtraw, Palmer and Kahn (2010) show that such a mechanism can be useful as a way to support prices and thereby maintain incentives for investment in clean technologies, and Grüll and Taschini (2011) provide an analytic exposition. Fell et al. (2012a) examine a soft price collar in which the prices are enforced incompletely with a limited volume of additions or subtractions from the expected cap. They find that increasing the size of the reserve of allowances lowers costs, but with a diminishing effect as the reserve is expended. Hence, although increasing the size of the reserve would, if triggered, increase emissions, the emissions uncertainty associated with changes to the cap can be limited while achieving considerable assurance about overall cost. Some authors have dismissed the idea of a price collar in the context of free allocation because it suggests a contingent property right, which would be taken away or repurchased by the government if prices fell and allowances were retired. However, over time, cap and trade program design has migrated to auctioning of allowances in the North American and European trading programs, and that makes possible the use of a reserve (minimum) price in the auction to enforce a floor price in the market. This approach to enforcing a price floor can be implemented even with free allocation of allowance value to compliance entities, where those who are awarded free allowances are required to consign some or all of them to be auctioned and then are the recipients of the revenue associated with their portion of the allowances sold at auction (Burtraw and McCormack 2016). Auction reserve prices are also the mechanism through which additional allowances are brought into the program when allowance prices reach price ceiling triggers.

3. Price Responsive Allowance Supply

Existing programs have incorporated lessons from the economics literature on cost containment into their policy designs. All of the North American carbon markets have introduced hard price floors, meaning that no allowances sell in the auction below the reserve price, thereby constraining the supply and supporting the market price. Price ceilings, or cost containment reserves (CCRs), to date are "soft" meaning that a limited number of additional allowances are available at specified prices, although California has recently amended its program to include a hard price ceiling beginning in 2021. In the price range between the floor and cost containment reserve there is no effect on price when demand for emissions allowances changes. Figure 1 illustrates how lower-than-expected allowance demand affects allowance market clearing prices and sales volume in the context of the current market design in the Regional Greenhouse Gas Initiative. As illustrated, low demand reduces allowance prices without having any effect on the number of allowance sold at auction, and therefore, no effect on emissions.

The figure illustrates a dilemma. Additional actions may be taken by cities, states, companies, or individuals in the region to reduce emissions associated with electricity consumption based not on the price of CO_2 emissions but for other environmental reasons. These additional efforts lead to an economic benefit for all the states in the region in the form of lower allowance prices, but they do not yield additional emissions reduction benefits. We refer to this as the "waterbed effect" because reducing emissions in one place simply makes available allowances to emit CO_2 in another place.

Figure 1. Supply Schedule with Price Floor and Cost Containment Reserve



A price responsive supply schedule would recover some of the additional contribution to emissions reductions associated with a decline in the equilibrium price in the auction. In most commodity markets, when the price of a good falls, less of that commodity enters the market. To accomplish this outcome in an allowance market the supply schedule would establish a price step or multiple steps, or a continuous ramp, above the price floor. Each step would be associated with a quantity of allowances that would not enter the market for a price below that price step. This feature is different from the price floor that applies to all allowances. A price step would apply to a specified quantity of allowances and could coexist with the price floor, below which no allowances would sell in the auction. There could be multiple price steps associated with specified quantities, forming a discrete price schedule above the price floor, or there could be a continuous schedule.

Figure 2 illustrates the influence that a supply schedule with a single step below the anticipated equilibrium price would have on the market if the demand for emissions allowances fell from its expected level to a low level. In this case the schedule would reduce the number of allowances entering the market, and the reduced supply would support the allowance price. As illustrated, the equilibrium allowance price would settle on the price step. If demand were even less, the equilibrium price would fall below the middle price step.

A supply schedule with multiple price steps could be implemented with specified prices and quantities of allowances associated with each price step. Figure 3 displays the same demand curves with several price steps. If demand fell to a low level, the equilibrium price in the market could fall below the highest price step to the second one, or potentially fall even further. One of the characteristics of a multi-step schedule is that the chance that any one step would ultimately determine the allowance price is less than under a single-step schedule. A continuous supply schedule would make supply even more responsive to incremental changes in allowance demand.

The price responsive supply schedule would help mitigate the waterbed effect because it enables a sharing of the benefits of falling allowance demand between economic savings and emissions reductions as some of the downward pressure on prices is translated into a reduction in the supply of allowances. This sharing of benefits would help preserve the incentive for policy initiatives by state and local governments, and voluntary actions by businesses and individuals, to pursue emissions reductions in addition to and beyond those required by the RGGI cap.

The price responsive supply schedule also might help the allowance market function more efficiently. The large vertical portion of the allowance supply schedule makes possible large unanticipated changes in allowance prices that can affect incentives to invest in clean sources of generation or energy efficiency that would help reduce emissions on an ongoing basis.

If investors make decisions based on their assessment of the probability distribution over future prices, then the price-responsive supply schedule would remove part of the risk of low prices.

In addition, when prices fall, compliance entities may purchase allowances in excess of their current compliance obligations in anticipation of a strengthening of the cap during a future program review. The price responsive supply schedule might proactively reduce the incentive to acquire large private banks while lessening the need for large cap adjustments during program review, as has occurred in some programs.

Figure 2. A Price Responsive Supply Schedule with One Step and Changes that Result from a Low Demand for Emissions Allowances

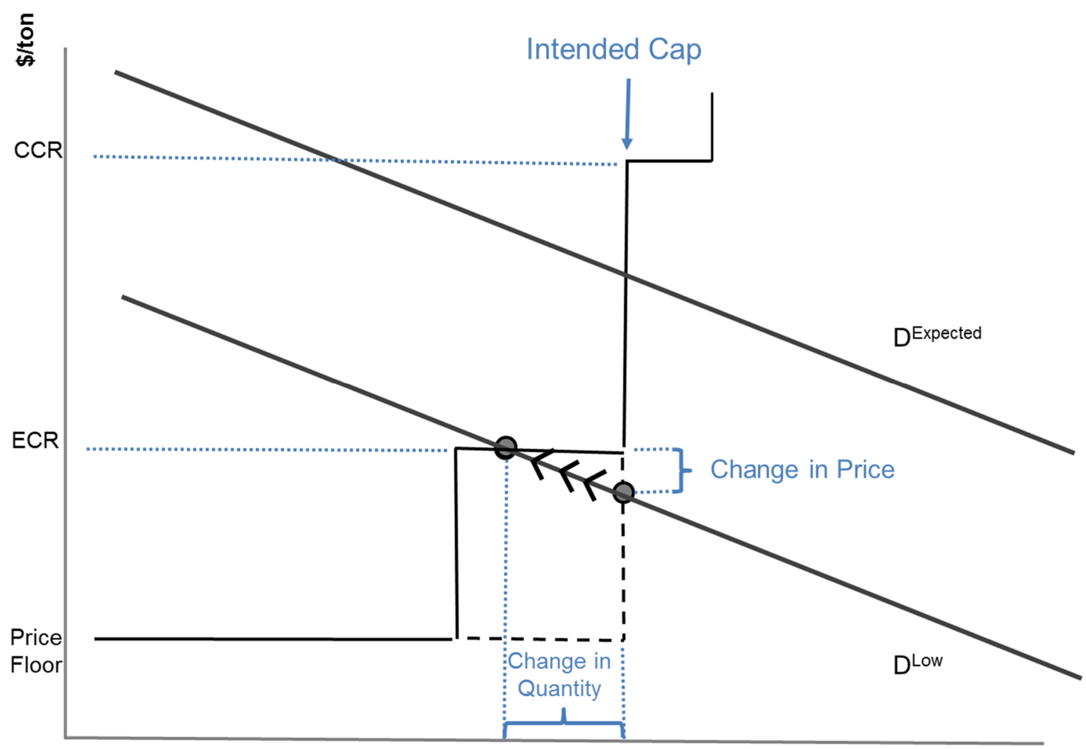
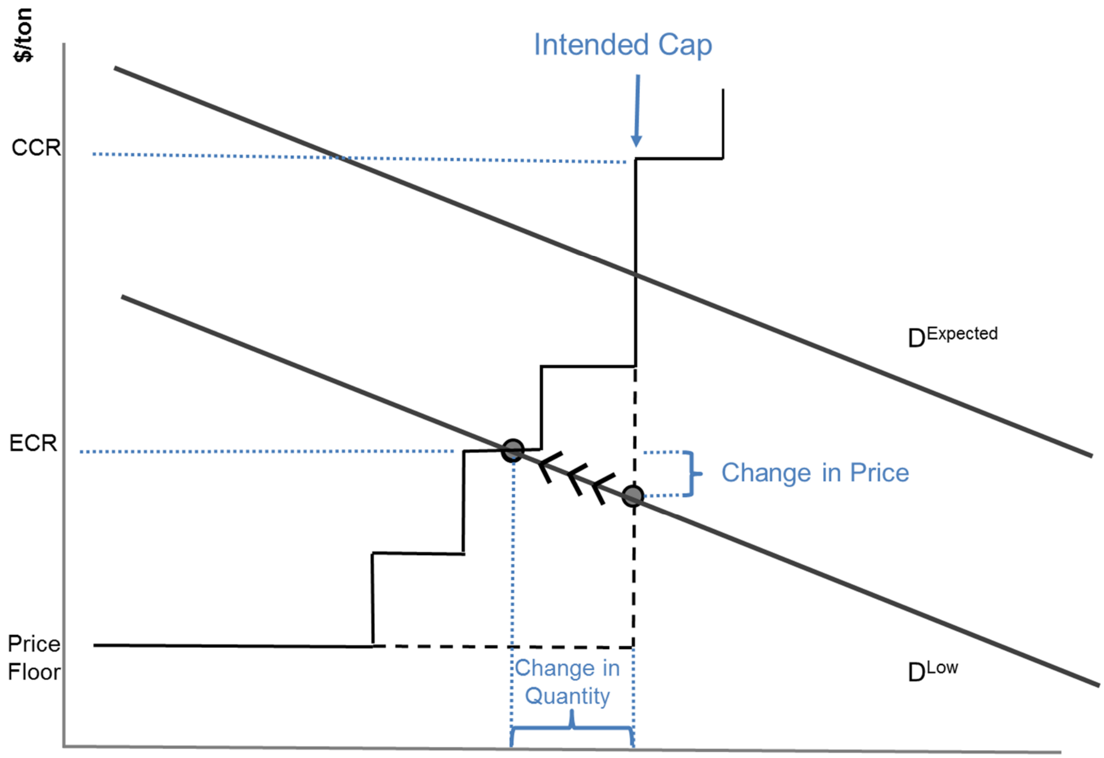


Figure 3. A Price Responsive Supply Schedule with multiple steps and changes that result from a low demand for emissions allowances



4. Implementing Quantities with Prices: An Example from RGGI

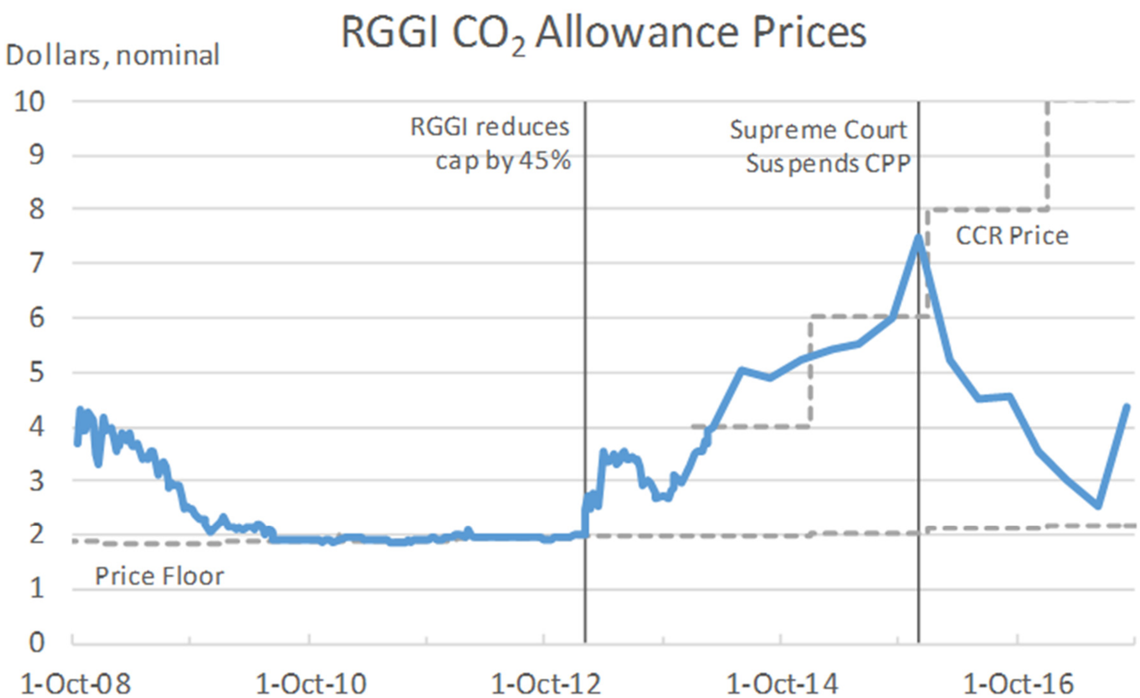
While most of the economics literature on policy design features to ameliorate unexpected cost outcomes in emissions cap and trade programs has focused on mitigating adverse effect of high side cost spikes, most of the experience in allowance markets has been that allowance prices end up being lower than expected. This experience and the factors that contribute to it are described in the context of several existing allowance trading programs in Burtraw et al. (2018) and in the context of the EU Emissions Trading System specifically by Ellerman and Buchner (2008) and Koch et al. (2014). Murray and Maniloff (2015) look at emissions reductions within the first several years of the RGGI program and find that unanticipated changes in the economy and in fuel prices and other energy policies, including policies promoting energy efficiency, account for roughly half of the emissions reductions in the RGGI region after the program went into effect, contributing to lower than expected demand for allowances and lower than expected allowance prices.

Both low and high-side cost containment have been features of RGGI since its inception in 2009. As the first cap-and-trade program for CO_2 emissions anywhere in the world to auction almost all of its emissions allowances, the RGGI program includes both an auction reserve price to help support program based emissions reductions in the face of lower than expected costs and a cost containment reserve.[1] Over time, the rules of RGGI have evolved and continue to do so. A 2012 Program Review led to a reduction in the trajectory of the emissions cap and the retirement of all allowances that were not sold at previous auctions.

Figure 4 shows the clearing price results of all 36 allowance auctions beginning with the first two auctions that occurred just prior to the cap coming into effect in 2009 plotted on top of the quarterly CO_2 emissions outcomes in the RGGI states. The graph reveals that after 7 initial auctions where prices cleared above the floor, auctions cleared at the floor price for eleven quarterly auctions. Then, prices started to head upward beginning in 2013, after the 2012 Program Review had reduced the number of allowances that would enter the market beginning in 2014. This was also the beginning of the second term of the Obama Administration when EPA started to formulate the Clean Power Plan to regulate CO_2 emissions from the electricity sector under the Clean Air Act. Anticipation of these regulations and the role that RGGI allowances could play in Clean Power Plan compliance likely contributed to increased allowance demand and clearing prices rose high enough to trigger the cost containment reserve in both 2014 and 2015 before falling again, starting in 2016. Thus, both the price floor and the price ceiling have been called into action during the first 9 years of the program.

[1] In 2017, the RGGI auction minimum reserve price as set at $2.15 per ton and it is scheduled to rise at 2.5 percent per year going forward. The cost containment reserve was set to introduce 10 million additional tons at a a price of $10 per ton in 2017 and also is scheduled to rise by 2.5 percent per year thereafter. As a result of the 2016 program review, beginning in 2021 the cost containment reserve will be set at 10 percent of the emissions cap level (roughly 7.5 million tons in 2021 and declining at 227.5 thousand tons per year thereafter) triggered at an initial price level of $13 per ton that grows at 7 percent per year thereafter.

Figure 4. Allowance Prices in RGGI



Note: Auction prices are used where market prices are not available.
Sources: Thomson Reuters; RGGI.

Substantial declines in the price of natural gas over the past decade as a consequence of the introduction of fracking technology and the resulting abundance of supply have reduced reliance on coal-fired generation and thus lowered demand for CO_2 emissions allowances. There is also uncertainty about how much electricity demand will grow over time and demand growth has been slowing relative to past trends and to expectations for several years. The economic recession reduced demand for electricity and emissions fell accordingly, but electricity demand has remained low as the economy has recovered. Operation of the existing nuclear fleet is also subject to uncertainty as low prices for wholesale electricity reduce nuclear profitability. Uncertainty about closure dates of certain large nuclear plants in the region affect the anticipated contribution of this non-emitting source to the generation mix. State and federal policies and programs to support renewable technologies also put downward pressure on emissions allowance prices, as do programs to promote energy efficiency in buildings. Uncertainty about future regulatory changes directed at CO_2 emissions, particularly at the federal level, may also reduce demand for allowances. All of these factors taken together suggest that the possibility for a slack emissions cap in RGGI is real.

As a result of its recently completed 2016 program review, RGGI is making some important program changes to take effect at the beginning of 2021. One of these changes involves introducing an additional level of price responsiveness in the allowance supply curve through the introduction of a single step allowance supply schedule, which has been termed an emissions containment reserve (ECR) in the context of the RGGI program. In the case of RGGI this ECR will withdraw up to 10 percent of the allowances from the market if the auction price falls at or below a trigger price of $6.00 in 2021, with that price rising at 7 percent per year in subsequent years.[2]

The implementation of a price responsive supply curve is simple and reproduces the mechanism of the current price floor and the cost containment reserve, but with additional price levels. For our analysis of the RGGI context in the next section, we adopt the language that RGGI uses to describe the addition of an intermediate price step and refer to this particular intermediate price step feature as the ECR. All of these mechanisms — the price floor, CCR and ECR — have minimum prices that are implemented as specific reserve prices in the auction, that is a minimum acceptable bid on a specified quantity of allowances. This is a familiar feature on platforms that sell goods in an auction setting. For example, one can observe the same kind of feature on eBay, where one can specify a minimum acceptable bid for items that are posted for sale.

5. Simulating the Emissions Containment Reserve (ECR) in the RGGI Program

We use the RGGI program as a laboratory to study the effects of a price-responsive supply curve, focusing exclusively on the empirically relevant prospect of a decline in allowance prices in RGGI, and the introduction of what RGGI terms an ECR on the allowance market and electricity market outcomes when allowance demand deviates from expectations. The RGGI program is represented in the Haiku electricity market model (Paul et al. 2009), which has been used in numerous other analyses of economic proposals and regulatory policies (e.g. Mignone et al. 2012). The model provides a partial equilibrium economic representation of investments and retirement of generation resources in 26 regions in the 48 contiguous US states linked by transmission capacity, and operation of the electricity system during selected years over three seasons and four times of day through 2035. Fuel supply and electricity demand respond to

[2] Currently Maine and New Hampshire are not participating in the Emissions Containment Reserve so will not be witholding any of their allocated allowances from the auction show prices fall below the ECR trigger price.

equilibrium prices. The model is calibrated to the AEO 2016 projections of electricity demand, retail prices and gas fired generation.

RGGI completed a program review in December 2017 that altered the path of the emissions caps beginning in 2021.[3] Our base case assumptions in the simulation model are comparable to the current design of the RGGI program , and to the ICF assumptions used in the Integrated Planning Model (IPM) simulations performed on behalf of RGGI in November 2016.[4] The Haiku model achieved comparable emissions allowance prices as IPM for our reference case scenario that included an annual reduction in the emissions cap equal to 3.5 percent of 2020 cap, or 2,736,132 million tons each year between 2021 and 2030.[5]

The path of allowance prices anticipated by the IPM model in November 2016 is illustrated in the top line in Figure 5. In 2020, the price was projected to be about $7 per ton, rising to about $9 per ton in 2026. However, in the April 2017 update to its modeling for RGGI, the allowance price projected by IPM fell to near the auction price floor in 2020, remaining near the floor for the subsequent decade, as illustrated in the bottom line. Important to our analysis, the changes that contributed to this update include changes to natural gas price projections (updated from AEO 2015 to AEO 2017), updated regional electricity demand projections and projections for cost and performance of renewables, and anticipation of additional renewable imports from Quebec and Ontario. These changes illustrate how, in just six months, unanticipated changes in market factors can influence the price of emissions allowances by changing market demand. Once determined through regulatory negotiation, the supply of allowances in trading programs is fixed until and if it is revised during a subsequent program review, but the demand for allowances can change quickly.

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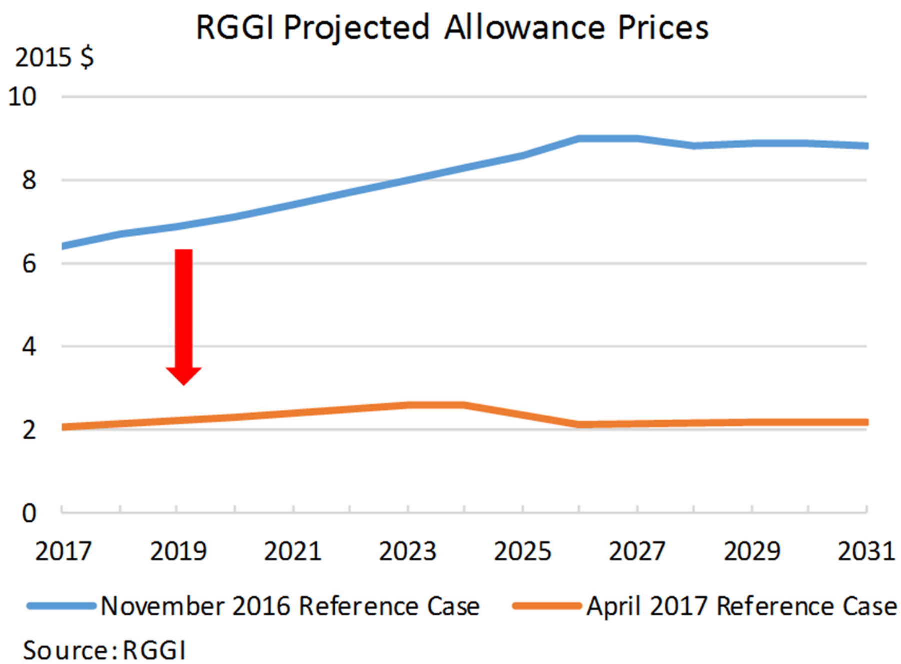
[3] The Model Rule Update includes adjustments to the size and structure of the cap and apportionment to states, adjustments to the cost containment reserve, and the introduction of an emissions containment reserve. See: https://rggi.org/docs/ProgramReview/2017/12-19-17/Summary_Model_Rule_Updates.pdf.

[4] http://www.rggi.org/design/2016-program-review/rggi-meetings.

[5] This schedule is based on the 2020 cap before an adjustment that was approved in 2012 to account for the large privately held bank of emissions allowances. That adjustment reduced the cap from 2016 through 2020, culminating in a 28 percent reduction in 2020 from 78,175,215 tons to 56,283,807 million tons. In addition, a bank of publicly state-held allowances that did not sell when prices were at the price floor was permanently retired.

Figure 5. IPM Projections of RGGI Prices Changed with New Assumptions



The reference case in the Haiku model has a cost profile similar to that anticipated in November 2016 by IPM. In modeling the 3.5 percent annual reduction in the allowance cap, we project an allowance price in 2020 of $8.10 per ton that rises at 5 percent per year over the subsequent decade, reflecting the opportunity cost of holding emissions allowances in the allowance bank. We assume the allowance bank is exhausted in 2030. The cost containment reserve is not relevant at the range of prices we explore. Allowances that are not sold due to the implementation of the ECR are retired.

5.1. Modeling Unanticipated Outcomes in the Electricity Market

We explore factors that could put downward pressure on allowance prices in the same way that the factors modeled by IPM in April 2016 did. We acknowledge that unknown factors outside the model are likely to have important additional uncertain influences on allowance demand that influence the allowance price. In our modeling, we describe six possible unanticipated outcomes in three conceptual groups.

Secular Outcomes

- Low Demand Growth: electricity demand growth is based on the AEO 2016 "Low economic growth" case which has lower demand nationally than in the AEO Reference case

- High Natural Gas Prices: natural gas supply is based on the AEO 2016 "Low oil and gas resource and technology" case which has higher natural gas prices than the AEO Reference case

Policy Outcomes

- More Energy Efficiency: $2.5/MWh system benefit charge funds energy efficiency programs for electricity end-users in 2020 and thereafter in all RGGI states
- Expanded RPS: RPS targets are 5% above currently stipulated targets in 2020-2024 and 10% above in 2025 and thereafter in all RGGI states

Resource Outcomes

- Hydro: expanded hydro (1050 MW @ 100% capacity factor) power imports from Quebec to New England
- Nuclear: delayed retirement of nuclear facilities that are otherwise scheduled for retirement during the 2020s

Each of these potential unanticipated outcomes is modeled separately and in groups of two (as indicated under the headings above), in groups of four (combining pairwise combinations of the headings above) and altogether as one group. The RGGI allowance price outcomes for the year 2020 with no ECR are reported in Table 1. The numbers in the first row show the allowance prices when each scenario is modeled separately. The other rows show results of the scenarios in different combinations.

Table 1. Allowance Prices [$/ton] with no ECR in 2020 Under Various Unanticipated Outcomes (2011 dollars)

<table>
<tr><th>Ref Case</th><th>Low Demand</th><th>High NG Prices</th><th>More EE</th><th>Expanded RPS</th><th>Hydro from Quebec</th><th>Delay Nuke Retirement</th></tr>
<tr><td>8.2</td><td>8.0</td><td>8.6</td><td>7.4</td><td>7.5</td><td>7.7</td><td>7.0</td></tr>
<tr><td colspan="7">Uncertainties modeled as packages</td></tr>
<tr><td>Secular</td><td colspan="2">7.4</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Policy</td><td></td><td></td><td colspan="2">7.0</td><td></td><td></td></tr>
<tr><td>Resource</td><td></td><td></td><td></td><td></td><td colspan="2">7.0</td></tr>
<tr><td>Sec+Pol</td><td colspan="4">5.2</td><td></td><td></td></tr>
<tr><td>Sec+Res</td><td colspan="2">5.2</td><td></td><td></td><td colspan="2">5.2</td></tr>
<tr><td>Pol+Res</td><td></td><td></td><td colspan="4">5.5</td></tr>
<tr><td>All</td><td colspan="6">4.0</td></tr>
</table>

5.2. Results without an Emissions Containment Reserve

In this and the following sections, we assume an annual reduction in the emissions cap over the next decade equal to 3.5 percent of the unadjusted 2020 emissions cap and examine market equilibria given potential unanticipated outcomes affecting allowance demand that are described in Table 1.

In Table 2, we focus on results for the last row in Table 1 because it has the most significant effect on the demand for allowances and illustrates the greatest changes in equilibrium outcomes. The first column of results in Table 2 indicates the model outcome in 2020 under the reference case with expected allowance demand and without an ECR that the electricity price is projected to be $143/MWh. Under the low allowance demand scenario without an ECR the electricity price falls to $140/MWh. The model anticipates reduced fossil generation in RGGI, but a larger share of that generation is achieved with coal, as indicated by the 29 percent increase in SO_2 emissions. In effect, the lower electricity demand and lower allowance price make room for more emissions intensive generation under the cap yielding a greater role for coal, even as nonemitting generation also increases due to assumptions about state-level support for renewables and increased hydro imports under this scenario. With no ECR in place, the same number of allowances are issued as under the reference case, but the reduction in emissions from covered sources in 2020 leads to more intertemporal banking. The lower allowance price leads to a reduction in the allowance value of over 50 percent, implying a decline in funding of various program-related activities, including support for energy efficiency.

Table 2. Simulation Model Results for 2020 under Three Alternative ECR Designs

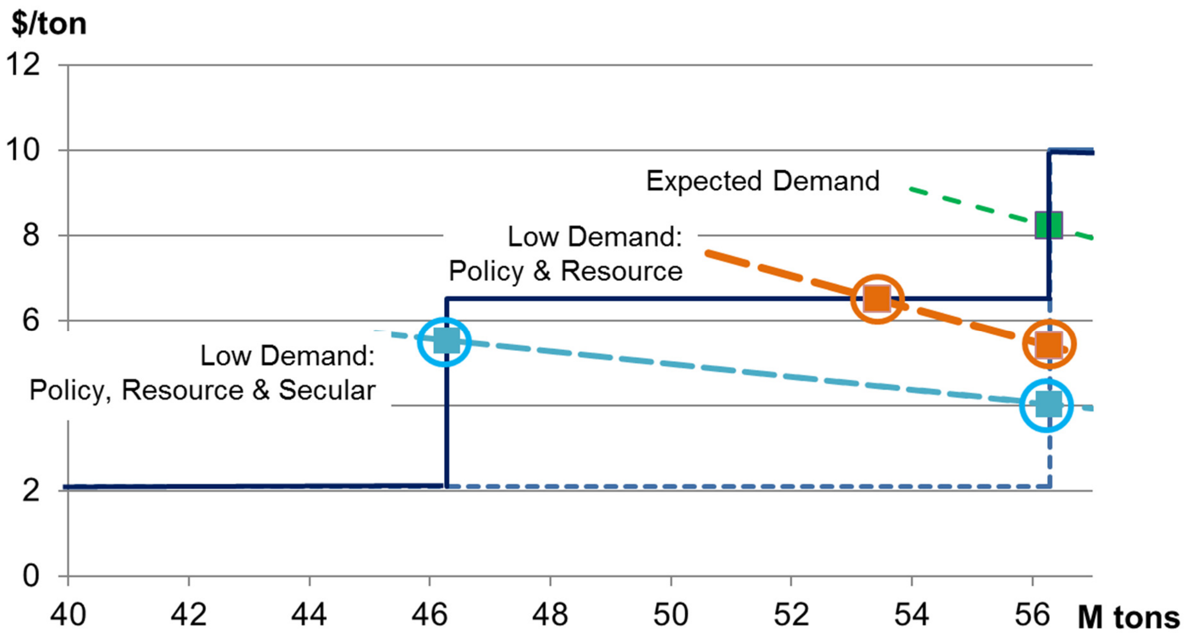
3.5% Annual Cap Reduction 2020 Results (2011 dollars)	**Reference Case**	**Low Allowance Demand**: Policy, Resource and Secular Unanticipated Outcomes			
	No ECR	No ECR	One Step ECR (10Mtons)	Three Step ECR (15 Mtons)	Ramp ECR (17.5Mtons)
Retail Electricity Price ($/MWh)	143	140	141	141	141
Fossil Generation (TWh)	143.5	112.1	101.7	107.6	106.4
Nonemitting Generation (TWh)	152.6	160.3	166.4	162.6	163.3
Allowance Price ($/ton CO_2)	8.2	4.0	5.3	5.0	5.0
RGGI Covered Emissions (Mtons)	72.3	70.1	62.5	66.6	65.8
SO_2 Emissions (Mtons)	10.4	13.4	11.8	12.8	12.7
Allowance Value (M$)	463	226	246	253	250
Incremental Leakage (%)	--	--	24%	26%	28%

5.3. Results with a Single Price Step

We explore three possible designs for the ECR. The first design is a single step ECR that would apply a minimum (reserve) price of $6.50/ton to ten million allowances (tons) per year beginning in 2020 and rising at 5% per year after that. Figure 6 illustrates the influence of the ECR under the expected level of allowance demand and two scenarios with reduced demand. The policy and resource scenario would yield an allowance price of $5.50 in 2020 in the absence of an ECR; however, the one-step ECR reduces the number of allowances entering the market and supports a market-clearing price equal to the ECR price step at $6.50.

The policy, resource and secular scenario represented in Table 2 leads to even lower allowance demand. The allowance price falls to $4 in the absence of the ECR, but with the ECR the allowance price increases to $5.30. Figure 6 illustrates that all of the ECR allowances are withheld from the market and the price falls below the ECR price level. Hence, one cannot suggest the ECR sets the price in the allowance market in the way that a minimum auction price might. The one-step ECR leads to a small recovery in the electricity price to $141/MWh, still below the level anticipated in the reference case. The constrained supply of allowances contributes to a reduction in fossil generation and a slight increase in nonemitting generation. Emissions of SO_2 are reduced by over half of the increase that resulted from low allowance demand in the absence of the ECR, but they are still 13 percent greater than in the reference case. Allowance value recovers by $20 million with this version of the ECR. Finally, we observe incremental leakage of 24 percent; e.g. the emissions reduction in RGGI associated with the ECR leads to a bounce back of emissions from uncovered sources in RGGI and in neighboring regions of 24 percent of that reduction.

Figure 6. One-Step ECR Outcome with Unanticipated Demand Changes



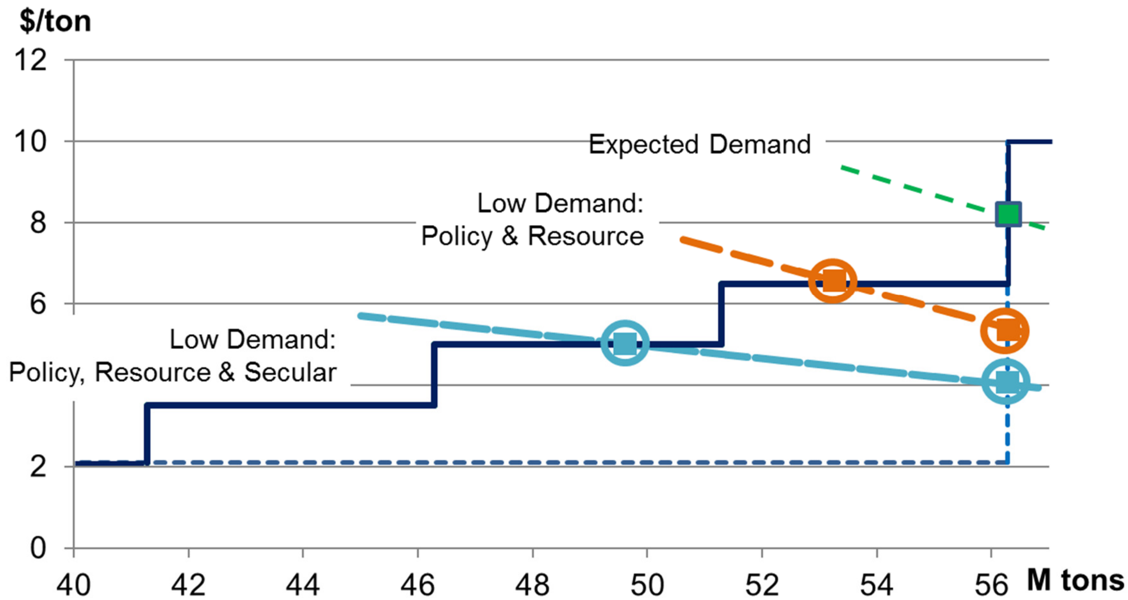
5.4. Results with Multiple Price Steps

In this section, we describe an ECR that has three steps implemented at $6.50, $5.00 and $3.50. Each step applies to 5 million tons in the auction. We note that this design is not necessarily more or less stringent than the one-step approach, but it can lead to different outcomes.

Figure 7 shows the same allowance demand scenarios as Figure 6. Under the policy and resource demand scenario the outcome is like the one-step scenario. That result occurs because we constructed the top step of the three-step ECR at the price level of the one-step scenario, and the auction clearing price lands on this portion of the ECR. However, the result is different with still lower allowance demand under the policy, resource and secular scenario. More allowances are issued under the three-step ECR, and the auction clearing price is lower, than under the one-step ECR.

The three-step ECR results in virtually no change in electricity price compared to the one-step ECR. Fossil generation recovers about halfway, compared to the one-step ECR, reflecting the lower allowance price, and RGGI covered emissions are slightly higher in 2020. Emissions of SO_2 increase almost to the same level as in the absence of the ECR, allowance value grows slightly, and leakage is roughly the same as in the one-step ECR.

Figure 7. Three-Step ECR Outcomes with Unanticipated Demand Changes



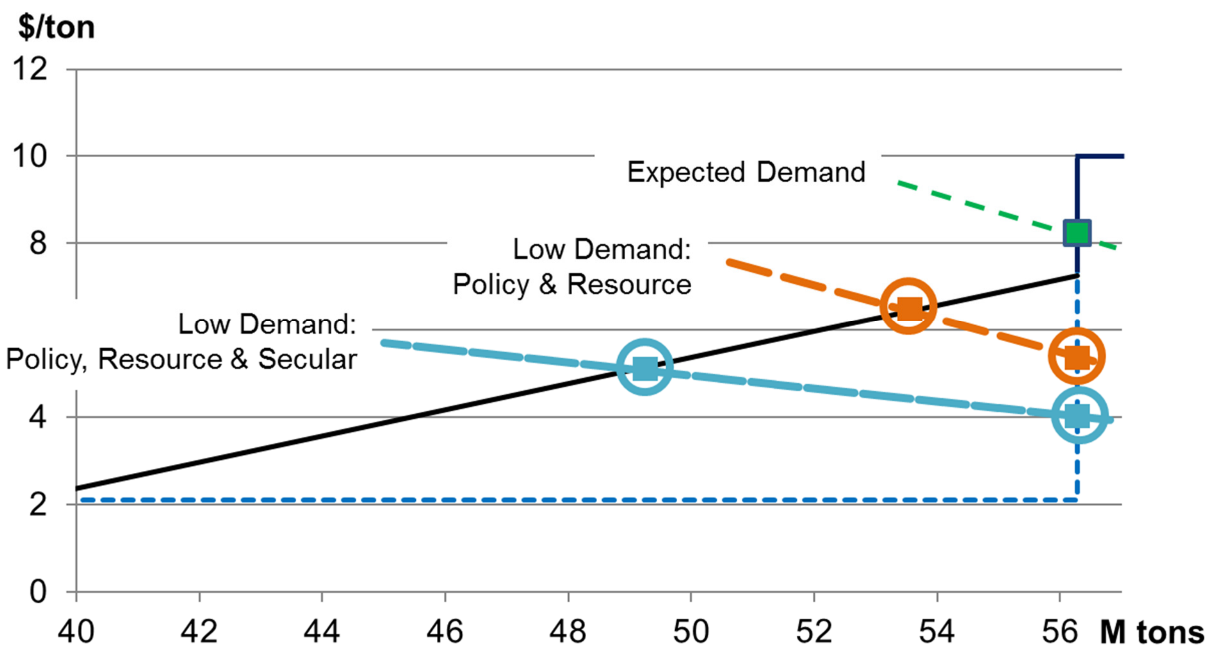
5.5. Results with an Allowance Supply Ramp

The third design we study in detail is a continuous schedule, or ramp, that begins at $6.50, the same value as the other two ECR designs we have discussed. The ramp declines linearly over 17.5 million tons until it meets the price floor at roughly 40 million tons. Figure 8 illustrates that virtually the same outcome is achieved under the policy and resource demand scenario as under the other two ECR designs. This outcome occurs by construction and is presented for illustrative purposes. However, with still lower allowance demand under the policy, resource and secular scenario the outcome varies from the other scenarios.

Slightly different levels of fossil and nonemitting generation result under the ramp, compared to the three-step ECR. The ramp achieves almost the same allowance price as the three-step ECR (the difference is obscured due to rounding), consequently, the ramp ECR has similar outcomes for emissions, allowance value and leakage.

It is important to observe that any one of these ECR designs is not necessarily more stringent than the other. However, they have different effects under various profiles for allowance demand, and the comparison illustrates how the market equilibrium is achieved.

Figure 8. Ramp ECR Outcomes with Unanticipated Demand Changes



5.6 Summary of Simulation Results and Sharing of Risks and Benefits

The results described above reveal that an ECR in RGGI yields a sharing of the benefits from reduced compliance costs when allowance prices are lower than expected. The ECR would abbreviate the price decline by reducing the supply of emissions allowances thereby creating environmental benefits in addition to economic benefits. While this modeling exercise has focused on outcomes that lead to lower than expected allowance demand, a similar sharing of risks and benefits between economic and environmental outcomes would also occur in a situation where demand for allowances is higher than anticipated and the CCR is triggered thereby raising the supply of allowances and alleviating some of the costs of a regulation.

We examined over two dozen scenarios that incorporate various unanticipated outcomes that reduce the demand for emissions allowances and the allowance price including those described in Table 1 and several other exploratory scenarios. Across these scenarios in the RGGI context we found that introducing an ECR has virtually no effect on electricity prices. We found it produces small and predictable changes in the mix of generation resources. For example, when the ECR is triggered and allowances prices rise, generation by emissions-intensive resources declines. The impact on the size of the bank is unpredictable. While changes in allowance demand are unanticipated by the policy maker, they are anticipated in the model, which minimizes the present value of costs. Banking behavior in the model responds to the timing of "unanticipated outcomes." For example, if the influences that exert downward pressure on electricity demand accumulate over time, then the ECR will be more relevant later in the decade and future reduction in allowance demand will be anticipated in the model. This effect is the prevailing trend in our scenarios and therefore there is typically more banking with an ECR. However, the opposite occurs in the laboratory experiments, which are discussed below.

In scenarios where the ECR plays its most influential role, for example as reported in Table 2, we find SO_2 emissions decline by up to 9 percent compared to no ECR, as the use of coal responds negatively to the increase in allowance prices under the ECR. Allowance value increases by up to 20 percent compared to the absence of the ECR as allowance price increases more than offset reductions in the quantity of allowances sold at auction. This increase enables increases in program related spending in RGGI. We also observe incremental leakage from the ECR hovers around 30 percent, meaning in effect that the cost of a ton of incremental emissions reductions achieved due to the ECR is 30 percent higher than is reflected by the change in the allowance price, or equivalently that RGGI has to reduce emissions by 1.3 tons in order to achieve 1 ton of emissions reduction from a global perspective.

The unexpected decline in the demand for allowances have various probabilities of being observed. From an ex-ante perspective informed by modeling, we conjecture a probability distribution of possible allowance prices both above and below expectations and that outcomes closer to the anticipated allowance prices are more likely than lower prices, at least in the near term. In this context, the benefits of a small deviation from the anticipated allowance price that does not cause the price to fall to an ECR price step accrue entirely to economic interests. A larger deviation that leads price to fall to an ECR price step would accrue to both economic and environmental interests. If the demand for allowances falls enough that all ECR allowances are withheld from auction, then the allowance price would fall below the lowest ECR price, leading to further gains for economic interests, until the price reaches the price floor. A CCR that introduces additional allowances when prices are greater than expected would have a converse effect, i.e. compliance costs increase initially as prices rise, but when the CCR price step is achieved additional allowances enable additional emissions to occur, and so on. A price responsive supply schedule can be envisioned to combine the ECR and CCR.

The structure of the ECR affects the pattern of sharing from low price realizations. With more price steps the benefits of low allowance demand are shared more evenly. Economic interests would get the first piece, environment the second, and so on alternating until the price reaches the price floor. Ultimately, the most equitable sharing would come from a continuous ECR, under which any decline in allowance price leads to fewer allowances entering the market.

6. Exploring the Emissions Containment Reserve in a Behavioral Context

The second approach to investigating the role of an ECR considers the way that individuals and markets respond. We pursue this using experiments to examine how the implementation of an ECR might affect trader behavior in the stylized setting of the economics laboratory where college students participate as research subjects in a simulated market with carefully structured incentives and real monetary pay offs. Experiments have been used previously to explore the likely effects of market designs in all of the key emission markets implemented to date, including RGGI, the SO_2 allowance trading program, the eastern US NO_x market, the EU ETS, and the California CO_2 cap-and-trade program. In the case before us, we are interested in measuring the effect of adding an ECR to a simulated market designed to mimic essential features of the current RGGI market.

6.1. Making It Look Like RGGI

An experiment comprises a set of treatments, where we vary one feature of the market at a time to observe the differences in outcomes that arise from changing just the one market feature. We explore each treatment with a series of laboratory sessions with human subjects to test for differences in outcomes that arise from the specific change to market design under examination.

We examine three treatments, one representing no ECR as a base case, and two others representing the addition of two forms of an ECR. These forms are a single-step ECR $8 for 16 allowances (25 percent of the initial cap) and, as an alternative, a linear ramp ECR that declines smoothly from the ECR trigger price to the auction reserve price, which is assumed to be $5 per ton. Each of these three treatments - baseline, step and linear - has precisely the same structure except for the introduction of an ECR and the way it is characterized.

Our laboratory setup presents subjects with a simplified version of the RGGI market, where the focus of the simulation is on essential features that drive trader behavior. Bidders can only acquire allowances in the auction; there is no spot market. However, the bidders interact through the determination of the equilibrium allowance price, which in turn affects the possibility that the ECR will be triggered. Each experiment includes 12 participants and each participant controls four “capacity units”, each of which produces one unit of output per period.

Half of the participants own low emitting units, which require one permit per unit of output, while half own high emitting units requiring 2 permits per unit of output.

Banking is unlimited. The price of electricity output varies between $30 and $40 per MWh with a probability of 50% each and the cost of production varies uniformly on [$10, $28] per MWh for low emitting "gas" units and on [$1, $28] for high emitters (coal). Each session has 30 periods with a cap that is declining over time from an initial value of 66 units to a final value of 37 units. The tightening of the cap gives participants the incentive to anticipate future increased scarcity and smooth the availability of allowances over time by banking in early periods for use in later periods. Previous experiments have shown participants to be very adept at smoothing the supply of allowances over time (Holt and Shobe 2016). What this implies for our sessions is that the price in early sessions will provide a good signal about the long-range tightness of the cap. If there were no smoothing, we would expect to see the price rise as the cap falls, but with effective smoothing, the price in early periods will be very similar to the price in later periods.[6]

Thus, if we observe a high allowance price, we can infer a relatively tight long-run cap. Alternatively, a low allowance price implies a relatively slack cap. In an allowance market like RGGI's, with a cost containment reserve, a tight cap would have a relatively high probability of triggering a release of allowances from the reserve. At the other extreme, a very slack cap would have a relatively high probability of having the auction close at the reserve price with some allowances unsold.Market participants know about the presence of the ECR and the reserve price and develop their bidding strategies that reflect expectations about future scarcity.

The purpose of the proposed ECR is to take account of the information that a chronically low price provides to the RGGI states. It is a signal that participants do not see the future scarcity of allowances rising so much that the declining cap cannot be managed, and that future compliance costs can be held down through banking.

Given the ability of market participants to consider future scarcity in today's actions, the presence of the ECR and the likelihood that it will be triggered and will reduce the long-term supply of allowances should have a predictable effect: it should raise today's price relative to a market without the ECR. The ECR could also change the incentive to bank allowances for the future. In theory, early banking could go either up or down in response to the presence of the ECR. If participants anticipate the future triggering of the ECR would make banked allowances more valuable in the future, then participants will choose to bank additional allowances. On the

[6] In the experiments we are assuming a zero discount rate for simplicity. This does not change the key results.

other hand, participants may see the ECR as lowering the total supply of allowances, so banking could conceivably fall and this outcome may appear intuitively more likely and, in fact, it is the outcome we observe in our preliminary experimental sessions.

Regardless of the pattern of banking, prices should be higher in a market with an ECR relative to a market without an ECR and this effect should occur even in sessions where the ECR is not actually triggered. Market participants will view the triggering of the ECR as a possible future outcome and will adjust their behavior accordingly. The presence of the ECR actually makes it somewhat less likely that the price level that would trigger the ECR will ever be observed.

6.2. Results from Preliminary Rounds

Preliminary results reported here are based on two sessions in each of our three treatments: no ECR, step ECR and linear ECR. The key results are presented in Figures 9 through 11. Figure 9 clearly shows a pattern of higher average allowance prices for sessions with an ECR than for sessions without an ECR. This is true for both types of ECR and prices are higher than the no ECR case in almost all periods.

In our sessions, the increased scarcity of allowances with either type of ECR reduces the amount of banking relative to the no ECR treatment. Nonetheless, while the ECR does result in a smaller number of allowances sold on average, the rise in price makes up for the reduced sales. There do not appear to be big differences in revenues across the two ECR treatments, although the linear ECR results in somewhat higher revenue; more sessions are needed to know if this difference is statistically significant.

Figure 9. Average Auction Price by Treatment by Round

Figure 10. Total Banked Allowances by Treatment by Round

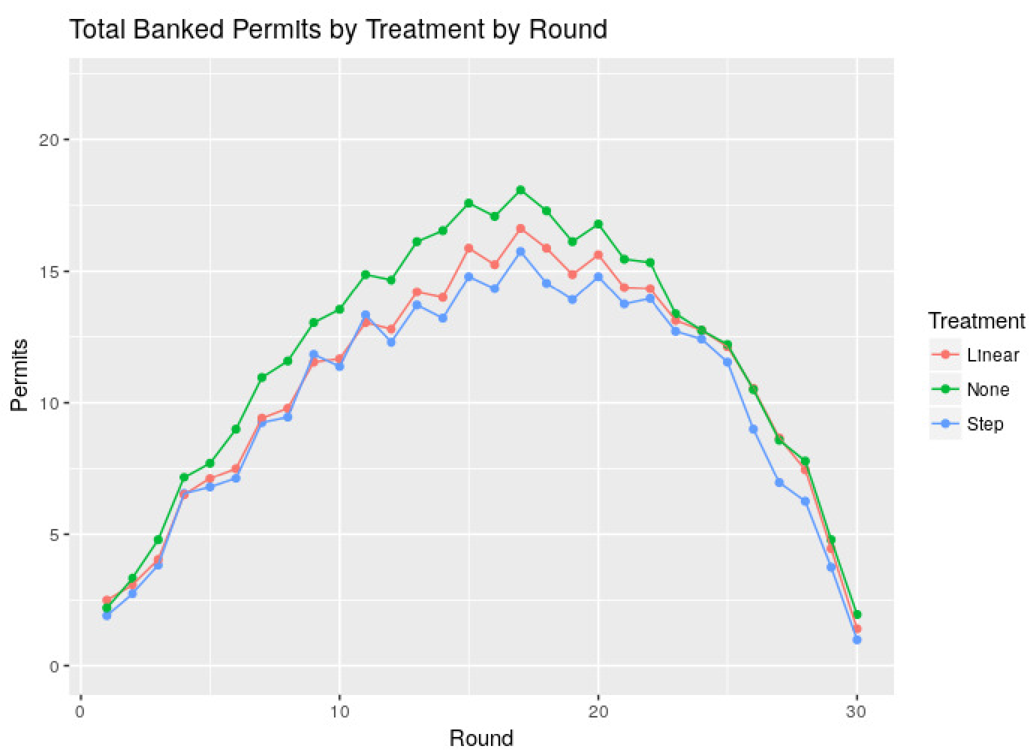
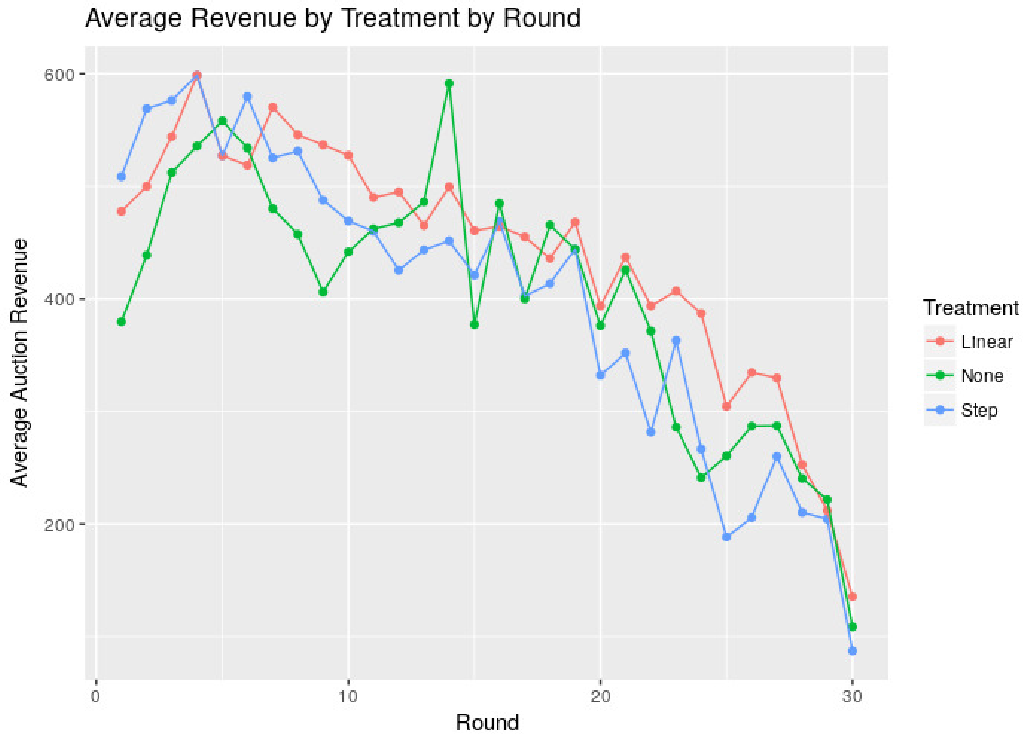


Figure 11. Average Revenue by Treatment by Round



7. Implementation of an Price Responsive Emissions Supply Schedule

Implementation of a price responsive emissions supply schedule is a small modification to the conventional emissions trading program. It involves decisions on five design features all of which were relevant as RGGI designed its approach to its ECR.

Number of intermediate supply curve steps: The decision about how many steps to include, or whether to use a continuous supply schedule, is informed by considerations of program simplicity. Because experiences with emissions trading have typically involved a perfectly inelastic supply of allowances with no price step, a single-step supply curve (potentially in addition to the price floor and high end CCR) may appear to be a smaller departure from the current program design. However, conceptually it is no simpler and in some ways more abrupt in its impact on the market equilibrium than a multi-step or continuous supply schedule, and hence it may be more difficult for market participants to anticipate outcomes in the face of uncertainty with a single intermediate step.

The substantive consideration in choosing the number of steps is the sharing of the benefits and risks of unanticipated levels of demand that would be realized if compliance costs and allowance prices differ from expectations. The sharing from a multi-step or continuous supply schedule is more even and continuous than from a one-intermediate-step supply schedule.

As noted, the multi-step and continuous approaches make it less likely that any particular price step ends up being the price that clears the allowance market.

Level of the supply schedule price step(s): The supply schedule price step(s) or the slope of the price ramp would be set between the minimum and maximum prices in the trading program and enforced through reserve prices in auctions. This process involves the identification of three values. One is the quantity of allowances under the cap that maps into the expected allowance market price. Second, if relevant, is the price floor (and cost containment reserve if offered in addition to the supply schedule), and third is the intermediate price step(s). Because of the uncertain nature of the underlying problem these are simultaneous considerations. Trading programs could approach this problem in a hierarchical manner, deciding first on the fundamental parameters of an anticipated price and price floor before setting the intermediate price step that would provide an incremental adjustment in the supply of allowances should demand for allowances end up deviating from expectations.

Price step quantities: If discrete step(s) are introduced, each will have to apply to a specified quantity of allowances that would not enter the market at prices below the respective price steps. A continuous function would not have quantities identified with each step but it would require identifying the quantity of allowances that would be brought into the price ramp.

Change in the price steps over time: With banking under the program, the Hotelling rule posits that the price of allowances will rise steadily at the real intertemporal opportunity cost of capital and many economic models enforce such a price path over time. In light of insights from economic theory, a policy maker might choose to stipulate that the price step also rises at this rate. However, the opportunity cost of capital is itself an uncertain variable and the specified time path for the levels of the price steps will affect its relevance as that uncertainty is resolved. More importantly, the Hotelling rule has generally not prevailed in air pollution allowance trading markets or in other commodity markets. The simple version of the Hotelling rule does not account for the many exogenous changes in technology, economic conditions, other policies and industry choices in the future that deviate from expectations at the time the cap-and-trade policy is established. Also, it assumes that the cap-and-trade program will remain in effect, but the existence of the program is itself uncertain. Given, these qualifications, an alternative to basing the rate of growth for price steps on the model-identified price path may be appropriate. If the price step is specified to grow at the same rate as the model-identified price path and the realized allowance price grows at a slower rate, then the price step would become more influential over time. Similar considerations apply to the rate at which the price floor and cost containment reserve increase over time.

Disposition of unsold allowances: When an allowance auction clears at a price at or below the level of a price step, there will be a smaller quantity of allowances sold than is available in the auction. There are several alternatives for how to dispose of allowances that are not sold. One is to roll the allowances forward to future auctions. A second is to use them to undergird the CCR, so that they would only re-enter the market if the auction cleared at very high prices. These alternatives, however, undermine the function of the price schedule approach to provide sharing between risks and benefits when compliance costs are low, which would be accomplished if the allowances were permanently retired. Conversely, if a price responsive supply curve led to the introduction of additional allowances to the market because allowance prices were higher than expected, regulators would have to decide where those allowances come from. In California, for example, revenues from the sale of these allowances would be directed to purchase emissions reductions from outside the program.

8. Conclusion

Economic advice for climate policy derives from identification of a first-best result in solving a global environmental problem. However, climate policy is taking shape at the level of individual nations and even sub-national jurisdictions. Nonetheless economic ideas have had an important influence in the emergence of regional cap-and-trade programs. These programs are designed around the concept of a perfectly inelastic supply of emissions allowances, which might be first best from a global perspective, but is not when implemented in a non-cooperative context. In practice these programs have added auction price floors and cost containment reserves; nonetheless, over a large range of potential allowance market equilibria, the quantity of allowances in existing trading programs is fixed. This approach has several disadvantages, including highly variable allowance prices and auction revenue, and it undermines the environmental effectiveness of additional voluntary actions taken by individuals and of other types of policies adopted by subsidiary jurisdictions within the emissions-capped regions. This limitation on environmental effectiveness can pose a major obstacle to further implementation of economic approaches and to further progress in reducing greenhouse gas emissions.

This paper recognizes that in practice existing cap-and-trade programs have begun to introduce price floors and cost containment reserves that are departures from perfectly inelastic allowance supply, although between these price points supply is inelastic. However, this evolution has begun to change the form of emissions trading programs with the addition of the emissions containment reserve in RGGI, which introduces a price step above the price floor but below the expected price. We identify several advantages of this design within a simulation model of the RGGI region and in laboratory experiments, including less price and revenue variability and greater incentives for voluntary additional actions to reduce emissions. The departure from conventional practice is a significant one, overcoming the difficult choice between price versus quantity instruments that has characterized over forty years of economic debate, and moving toward a design for environmental markets that more closely resembles that of other commodities. Importantly, we recognize the supply of emissions allowances as instructions from the regulator to the market, reflecting the outcome of domestic regulatory negotiations. These instructions reveal a willingness to pay for emissions reductions, and as prices fall or rise, supply falls or rises as well, as in other markets. We describe the set of decisions about design features that must be made in order to implement this approach.

As part of their 2016 Program Review, the RGGI states adopted an emissions containment reserve that sets a minimum price on a portion of the allowances available for sale at each RGGI allowance auction above the auction reserve price and below the price that is expected to clear the auctions. If RGGI compliance costs are lower than anticipated (i.e., low allowance prices clear the auctions), then the reserve would be triggered and some allowances would not enter the market. Fewer allowances in the market supports the allowance price, and implies fewer emissions within RGGI and gains for the environment.

RGGI's interest in considering price response allowance supply arises from the observation that the costs of compliance with cap-and-trade programs for airborne emissions worldwide frequently tend to be considerably lower than ex-ante expectations. This outcome has certainly been observed in RGGI as 11 of the 36 allowance auctions have cleared at the reserve price and with others clearing just above the reserve price. In the absence of the reform, low demand for emissions allowances leads to a reduction in allowance prices. Unless demand is so low that prices are at the auction reserve price, low demand and low prices are an economic benefit with no coincident environmental benefit. This result is a manifestation of what we call the "waterbed effect." An emissions reduction effort such as investment in energy efficiency undertaken by any entity in a RGGI state will simply make more allowances available to other RGGI entities and no additional emissions reduction is realized, at least until a potential cap adjustment as part of a subsequent program review. The waterbed effect undermines the incentive for environmentally motivated cities, states, companies, and individuals to take actions to reduce emissions associated with electricity consumption as any such actions may yield no climate benefit.

Some observers have expressed a concern that varying from an inelastic allowance supply might transform the quantity based program into one that determines the price in the allowance market. However, if the market price falls to the reserve price step then some allowances do not enter the market, which in turn has an effect on allowance prices, the mechanism does not determine the price. Our simulation modeling indicates that the allowance price may end up below the ECR price step or below multiple steps. Any allowance price at or above the auction reserve price (price floor) may clear the market and the ECR merely affects the quantity of allowances that enter.

A price responsive supply curve introduces new considerations with respect to the possibility of linking with other allowance trading programs, but they are strongly analogous to the considerations that a program such as RGGI already would take into account because of its price floor. Under the ECR, as under a price floor, if allowances are not sold by the RGGI states the allowance price will be supported. Our modeling indicates that this leads to a net increase in the revenue from the auction, but the benefits accrue even more strongly to the linked jurisdiction(s) that is able to sell all of its allowances at the higher price enabled by the ECR. Negotiation about linking may want to take this distribution of benefits into consideration.

RGGI has been seminal as a market-based regulation of CO_2 emissions in the United States and across the globe for introducing features that have broad appeal. RGGI was the first program to sell almost all of the emissions allowances by auction and, as such, the first to implement an auction reserve price. These features of RGGI have found their way into California's cap-and-trade program, in Quebec (which is now linked with California), and in Ontario. The emissions containment reserve appears to be another RGGI innovation that would better align incentives for individual actors in the region and help to better integrate cap and trade with companion efforts in cities and states and by private actors to promote clean energy and reduce CO_2 emissions. In a world where these companion programs will continue to exist and play an important role, the price responsive supply curve could serve as a model for other greenhouse gas cap-and-trade programs.

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