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Why Have Greenhouse Emissions in RGGI States Declined?

An Econometric Attribution to Economic, Energy Market, and Policy Factors

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Abstract
The Regional Greenhouse Gas Initiative (RGGI) is a consortium of northeastern U.S. states that limit carbon dioxide emissions from electricity generation through a regional emissions trading program. Since RGGI started in 2009, regional emissions have sharply dropped. We use econometric models to quantify the emissions reductions due to RGGI and those due to other factors such as the recession, complementary environmental programs and lowered natural gas prices. The analysis shows that RGGI has induced greater emissions reductions within the region than have been achieved proportionally in the rest of the United States, though some extramural leakage may have occurred.

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Introduction

The Regional Greenhouse Gas Initiative (RGGI) is a consortium of northeastern U.S. states that have agreed to limit the greenhouse gas (GHG) emissions of carbon dioxide (CO_2) from electric power generation through a regional emissions trading ("cap-and-trade") program.[1] Since RGGI came into effect in mid-2008, total emissions from the region's power sector have dropped substantially. Figure 1 depicts an index from 1990 to 2010 showing the change in income, population, electricity generation, and electricity emissions in RGGI states between 1990 and 2010.[2] The figure outlines the percent change of a certain factor indexed to its value in 1990. These data highlight the sharp decline in electricity emissions in the later years. In 2005, emissions were about equal to those of 1990, but by 2009, those emissions had fallen by approximately 30 percent. What is particularly interesting about that time period is that states started announcing their intention to join RGGI in the middle of the decade, but the program did not commence until 2009.

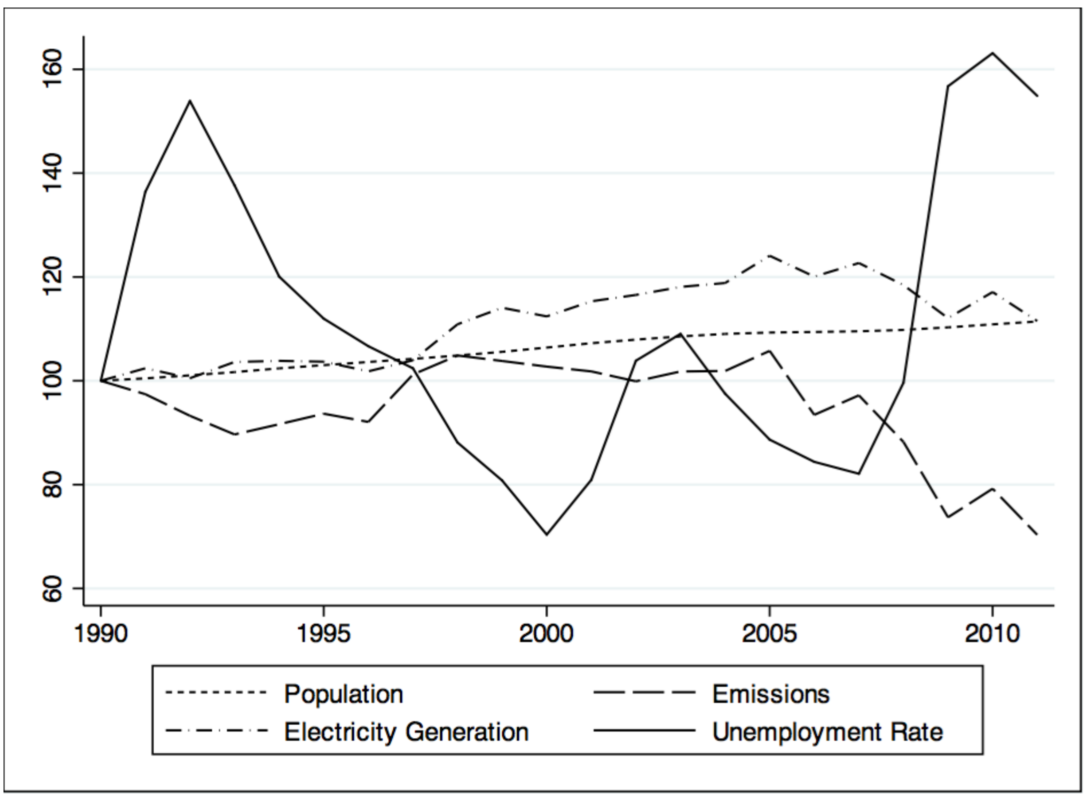

Figure 1. Trends in Electricity Emissions and Determinants, RGGI States, 1990-2011. Index (1990=100).

[1] From 2009 to 2011, the 10 RGGI states were Connecticut, Delaware, Maine, Maryland, Massachusetts, New

[2] Emissions and generation data are from the U.S. Energy Information Administration. Population estimates are from the U.S. Bureau of Economic Analysis. Statewide unemployment rates are from the U.S. Bureau of Labor Statistics. The population-weighted average presented here is the authors' calculation.

Meanwhile, electricity generation stayed about the same after 2005, and has risen significantly since 1990. This widening gap between emissions and generation suggests a decarbonization of power generation as it transitions from coal and oil, which emit much larger amounts of carbon per BTU of energy produced, to lower- or zero-emitting fuel sources, such as natural gas, nuclear power, and renewables, respectively. The shapes of the electricity generation and emissions functions are similar, usually increasing and decreasing in the same years as one another. They also share similar patterns of variation: as generation increases, emissions increase similarly.

Current emissions are not just well below historic levels—they are below the RGGI emissions cap. Retired allowances equaled more than one-fifth of the legislated emissions cap for the 1990–2010 period. As detailed below, the allowances were unsold because of a price floor, below which no RGGI auction bids can be accepted.

Taken together, these factors suggest that RGGI has been (1) extremely effective; (2) less stringent than it should be; or (3) overtaken by other economic, technological, and market factors that are driving emissions down; it may even reflect some combination of these qualities and circumstances (LeGrand 2013). Researchers (Tietenberg 2013; Stavins 2012; Hibbard et al. 2011; Environment Northeast 2011) have suggested four possible explanations for the dramatic emissions reduction:

- The RGGI program sends a price signal favoring relatively low-emitting sources and generates auction revenues to finance low-carbon and energy efficiency investments within the region.
- The economic crisis commencing in 2008 lowered economic activity, energy demand, and emissions.
- Natural gas became more widely available, due in part in to rapid expansion of hydraulic fracturing (“fracking”) technology.
- RGGI states are experiencing the impact of complementary state environmental programs such as renewable portfolio standards, which mandate that a certain share of electric power be generated by renewable (low- or zero-emitting) sources.

This paper attempts to quantitatively assign emissions reductions in the RGGI region to these and other factors through development of an econometric model of the U.S. electric power sector reflecting final demand for electricity, factor demand for alternative generation sources, and CO_2 emissions. The model is estimated with panel data from each of the 48 states in the continental United States for the period 1991 to 2011, allowing responses within the RGGI region and time frame to be differentiated from those in the rest of the country. The estimated model is used to simulate the energy and emissions effects of counterfactual scenarios to quantify the separate effects of the RGGI program, environmental policies, macroeconomic factors, and natural gas price shifts.

The analysis continues with a conceptual model that defines how the RGGI program works and how its cap-and-trade structure, along with other factors, influences emissions and price outcomes. The conceptual model informs discussion of the actual RGGI allowance auction price and quantity outcomes, followed by discussion of the influence of non-RGGI factors on emissions outcomes in the region. An econometric model of the power sector is used to estimate power demand, allocation of generation sources, and emissions with state-level time series data from 1990 to 2011. The estimated model is used to simulate counterfactual scenarios to quantitatively attribute emissions effects to policy and market factors. The paper concludes with a summary of key findings, caveats, and research recommendations.

The RGGI Program in Concept and Practice

RGGI is a regulatory cap-and-trade program under which participating states collectively establish a firm, legally binding cap on their region's electric power generation emissions for a specified period. The regulatory entity creates an allowance for each (short) ton of emissions allowed under the cap. A vast majority of the allowances are initially sold in an auction, but they can be resold on the open market to any party wishing to use them. For compliance purposes, a regulated power plant must submit a number of allowances to the regulator equal to the emissions it generates during the compliance period. Trading of allowances among compliance entities establishes a market price for those allowances, providing an incentive for all parties to reduce their emissions. Parties that can cut emissions less expensively than other parties can sell their allowances, enhancing the cost-effectiveness of emissions reduction efforts relative to the absence of trading (Montgomery 1972).

Cap-and-Trade Model

Figure 2 illustrates how an emissions trading program like RGGI creates an allowance ("carbon") market. To simplify the explanation, we use a static representation of the market for the compliance period of interest. Temporal dynamics within and between compliance periods can complicate matters, but the essence of the story can be captured with the static model. Here the regulator, RGGI, establishes an emissions cap of E^C. E^{B0} represents regulated facilities' baseline emissions—those we would expect to occur if no program were in place. Reducing emissions below this point (abatement) incurs costs for the generators. These costs are represented by the marginal abatement cost function, MAC_0, rising from right (more emissions) to left (less emissions) in Figure 2. The MAC function is an aggregate of all plant-level marginal cost functions within the region, and thus the point at which the function intercepts the emissions cap quantity is the region's marginal cost of meeting the cap. Given that entities within the region can trade allowances among one another, the marginal cost at the emissions limit will dictate the allowance market's equilibrium price, P_0. The program and the market it creates lowers regional emissions from E^{B0} to E^C at a marginal cost (price) of P_0.

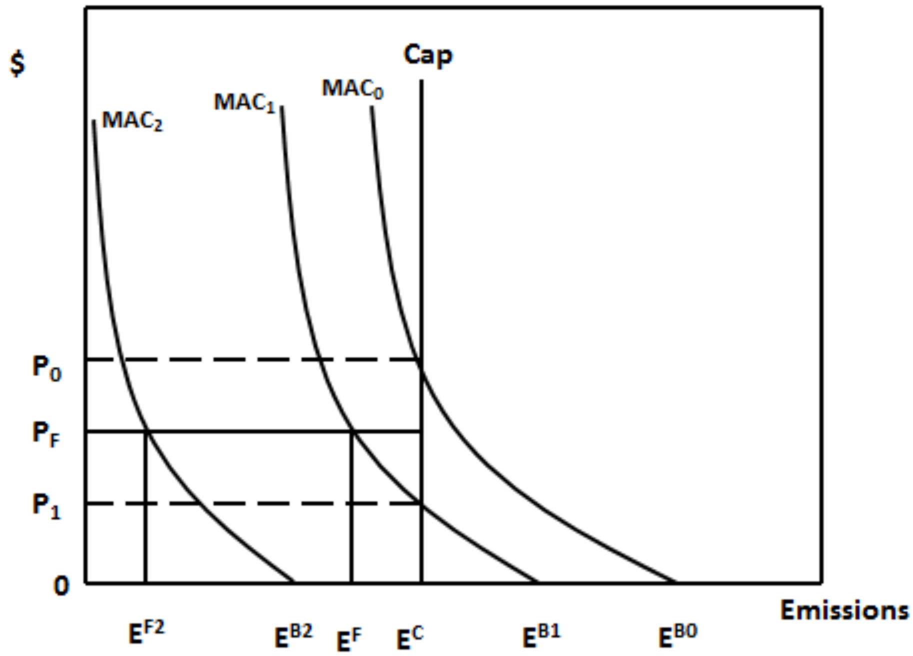

Figure 2. Baseline Emissions, Cap, and Carbon Price

The true baseline emissions quantity is uncertain because (1) exogenous factors affecting emissions, such as weather, energy market shocks, policy shocks, and macroeconomic variables, are random and unknown before the cap is set, and (2) once the cap is set, any estimate of baseline emissions without the cap is purely counterfactual and subject to estimation error. Thus, the true baseline may shift, say, from E^{B0} to E^{B1} in Figure 2. This inward shift, representing a decline in baseline emissions, might be due to a slump in economic activity affecting electric power demand or to changes in fuel markets that lead to some substitution of higher carbon-emitting fuels such as coal to lower-emitting fuels such as natural gas, as discussed below. Whatever its cause, this baseline emissions decrease reduces pressure on the carbon market. The new cost curve (MAC_1) originates at the lower baseline level and intersects the cap at a lower equilibrium market price, P_1. Here the cap is not as stringent relative to the baseline, and the price drops accordingly. In an even more extreme case, wherein the emissions baseline plummets to E^{B2}, a level that is below the regulatory cap, the cap is not binding. In this case, we would expect a market-clearing price of zero and no further abatement below E^{B2}.

Price Floor

RGGI has a price floor, established by a minimum reserve price below which bids will not be accepted at auction. If the total bids offered at the floor price are less than the total allowances available for auction, the remaining allowances remain unsold and are banked or retired by the regulator.

In its most recent revision, RGGI incorporated a cost containment reserve (CCR), which holds a set quantity of allowances aside and introduces them into the market through auction at a high end trigger price. The CCR offering provides a "soft" price ceiling by making extra allowances available to meet demand at the trigger price. If the CCR is sufficient to meet demand at the trigger price, that price will be a firm price ceiling. If the CCR is insufficient to meet demand at the trigger price, the clearing price can rise above it but will remain lower than it would have been without the CCR, hence the term *soft ceiling* (see Murray, Newell, and Pizer 2009). However, as discussed below, the history of RGGI has been one of low prices determined by the price floor. Therefore, we focus on the floor and ignore the CCR ceiling here.

The effects of the price floor are illustrated in Figure 2. When the baseline emissions and MAC function shift from (E^{B0}, MAC_0) to (E^{B1}, MAC_1), the market-clearing price drops to P_1 if all allowances under the cap are offered for sale. However, P_1 falls below the price floor, P_F, established by the program. If emitters cannot obtain allowances for less than P_F at auction, they will plan to abate emissions up to the point that the marginal cost of abatement equals P_F. This occurs at the emissions level E^F, which is below the emissions cap, E^C. As such, allowances in the amount of (E^C - E^F) go unsold, and emitters over-abate relative to the cap. This situation recently occurred in the RGGI states, as discussed below.
In summary, the difference between a prior expected baseline emissions rate of E^{B0} and an actual outcome of E^F can be attributed to different factors as follows:

$E^{B0} – E^{B1}$ = exogenous factors unrelated to emissions trading
$E^{B1} – E^C$ = "free market" price abatement induced by trading
$E^C – E^F$ = price floor-induced over-abatement

RGGI Program Auction Outcomes Since Inception
Figure 3 illustrates the outcomes of the RGGI quarterly auctions from their inception in late 2008 through 2013. The auctions in late 2008 were preparatory for the introduction of the cap in 2009. From 2009 to 2011, the cap was 188 million short tons per year for the 10-state region. New Jersey dropped out of RGGI after 2012, and the nine remaining states faced a reduced cap of 165 million short tons per year.

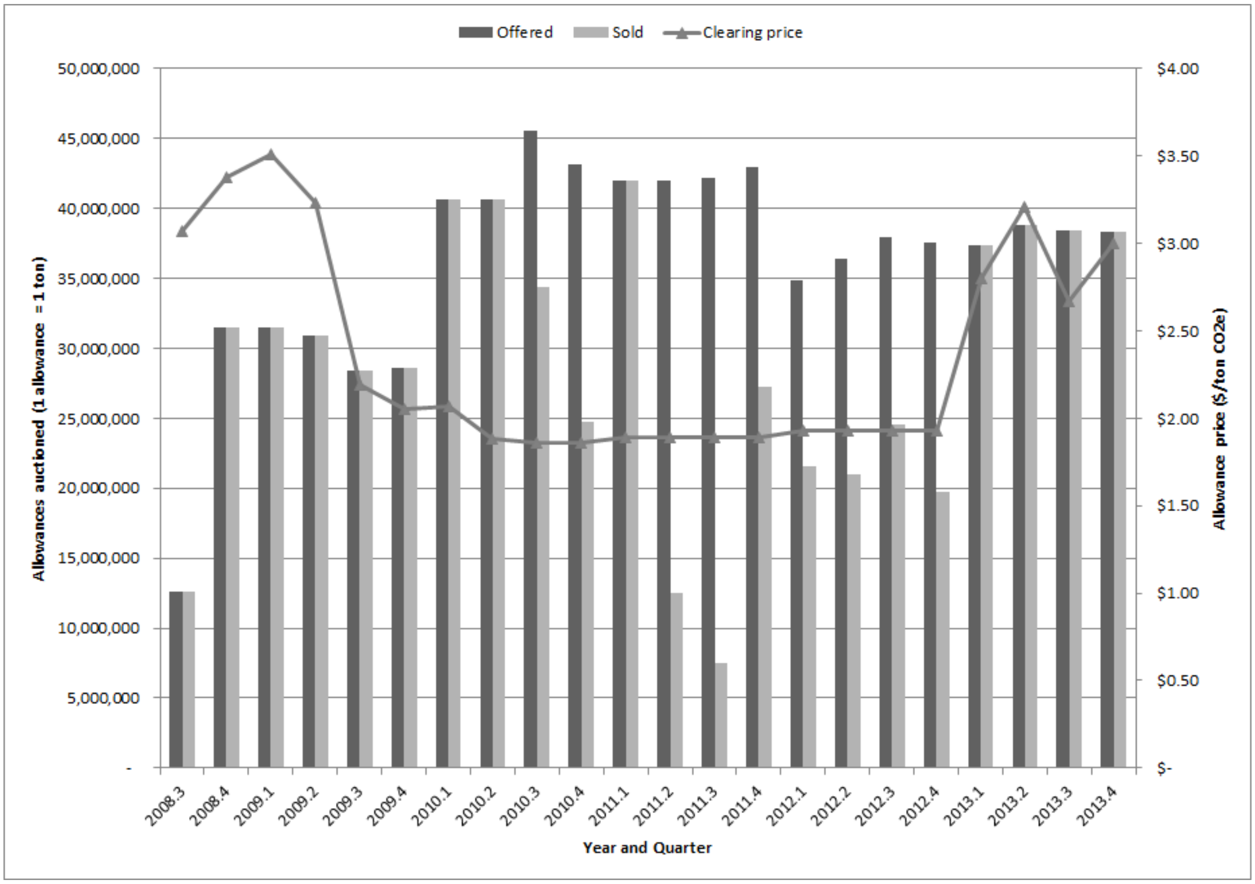

Figure 3. RGGI Auction 2008-13: Allowances Offered, Sold, and Clearing Price

Source: RGGI, 2014. Allowances Offered and Sold by Auction.
http://www.rggi.org/market/co2_auctions/results

The bar diagrams show the allowances offered and sold each period (see left vertical axis for units), and the line shows the market-clearing price (right axis). At the beginning of the program through mid-2010, all allowances offered at auction were sold. Prices started to decline in 2009, and by the third quarter of 2010, the price floor was triggered, and allowances went unsold at the floor price (just under $2.00) through the end of 2012, the end of the first RGGI period. From 2009 to 2012, more than 169 million allowance tons remained unsold, or 26 percent of the total allowance pool for that period (RGGI 2014). In January 2012, five RGGI states (Connecticut, Delaware, Massachusetts, New York, Rhode Island, and Vermont) announced that they would retire allowances that they were unable to sell in their state's auction for carbon allowances, rather than hold them for the subsequent compliance period, which they were initially entitled to do.

After a program review in 2012, the nine RGGI states implemented a 2014 cap of 91 million short tons, a 45 percent drop in the cap. That cap is slated to decline 2.5 percent each year from 2015 to 2020. These changes returned the market to one of allowance scarcity, wherein all allowances were sold at auction, pushing the price above the floor in 2013.

Key Exogenous Factors Affecting Emissions

As mentioned in the introduction, the decline in RGGI states' emissions is a result of numerous factors. The factors outside the RGGI cap-and-trade program generally believed to be most critical are (1) the economic recession and the subsequent decrease in economic activity and electricity use, (2) the increased availability and lower price of natural gas, and (3) complementary environmental policies. Each effect is discussed briefly below.

The Post–2008 Recession

The economic recession that gripped the region, country, and most of the world after 2008 may have played a role in driving down electricity generation. Reduced economic activity leads to a decline in energy use, resulting in fewer emissions and decreased demand for carbon allowances. From 2008 to 2009, both GDP and total emissions declined for the first time since 1990 (Figure 1). GDP and total emissions followed a similar trend in growth, although emissions have risen at a much slower rate than GDP in the past 20 years. Moreover, emissions continued to decline even after economic activity started to pick up after the recession.

New Natural Gas Discoveries

Natural gas is the lowest GHG-emitting fossil fuel, producing about 47 percent of the carbon dioxide per energy unit of coal (Moomaw et al. 2011). In its 2008 biennial assessment of natural gas reserves in the United States, the Potential Gas Committee of the Colorado School of Mines reported a 40 percent increase in available gas reserves since its previous assessment in 2006 (Potential Gas Committee 2009). This unprecedented growth can be tied to the discovery of shale gas fields that had been previously written off as inaccessible or not worth pursuing. Now that companies have developed the process of hydraulic fracturing (or "fracking"), in which a pressurized mixture of water, sand, and chemicals is shot through shale rock, creating fractures in the rock and releasing gas, the estimated size of U.S. natural gas reserves has greatly increased. This relatively sudden expansion of natural gas supply contributed to the price of natural gas plummeting 46 percent between 2005 and 2011, while the price of coal rose (see Figure 4).

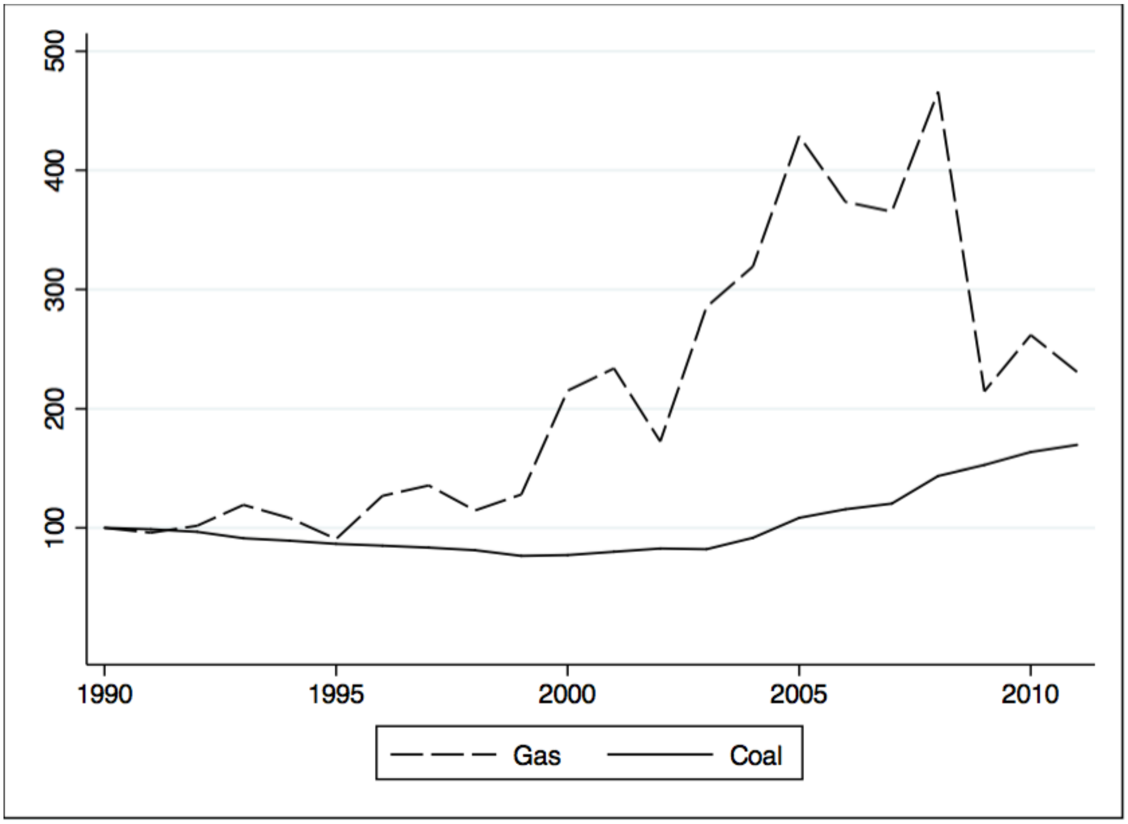

Figure 4. Coal and Natural Gas Nominal Prices Indexes (1990=100)

Source: Index derived using data from US EIA, Average annual prices for coal and natural gas. Release dates: (Coal December 12, 2013 http://www.eia.gov/coal/data.cfm#prices) Natural gas (wellhead) http://www.eia.gov/dnav/ng/hist/n9190us3A.htm Feb 28, 2014)

Together with the economic recession, a large supply of natural gas has kept the price of natural gas low over the past few years. The market has reacted to this low price by increasing use as a share of total energy generation (Figure 5). In 1990, natural gas accounted for 12 percent of electricity generation in the 10 RGGI states. By 2011, however, its market share had increased to approximately 40 percent. Meanwhile, the market share of coal dropped from 25 percent of total generation in 1990 to only 11 percent in 2011. This monumental shift from coal to natural gas generation within the region clearly has had a profound impact on the region's GHG emissions; however, the extent to which this impact is driven by pure energy market forces, environmental policy, or some combination of factors is one of the foci of the analysis below.

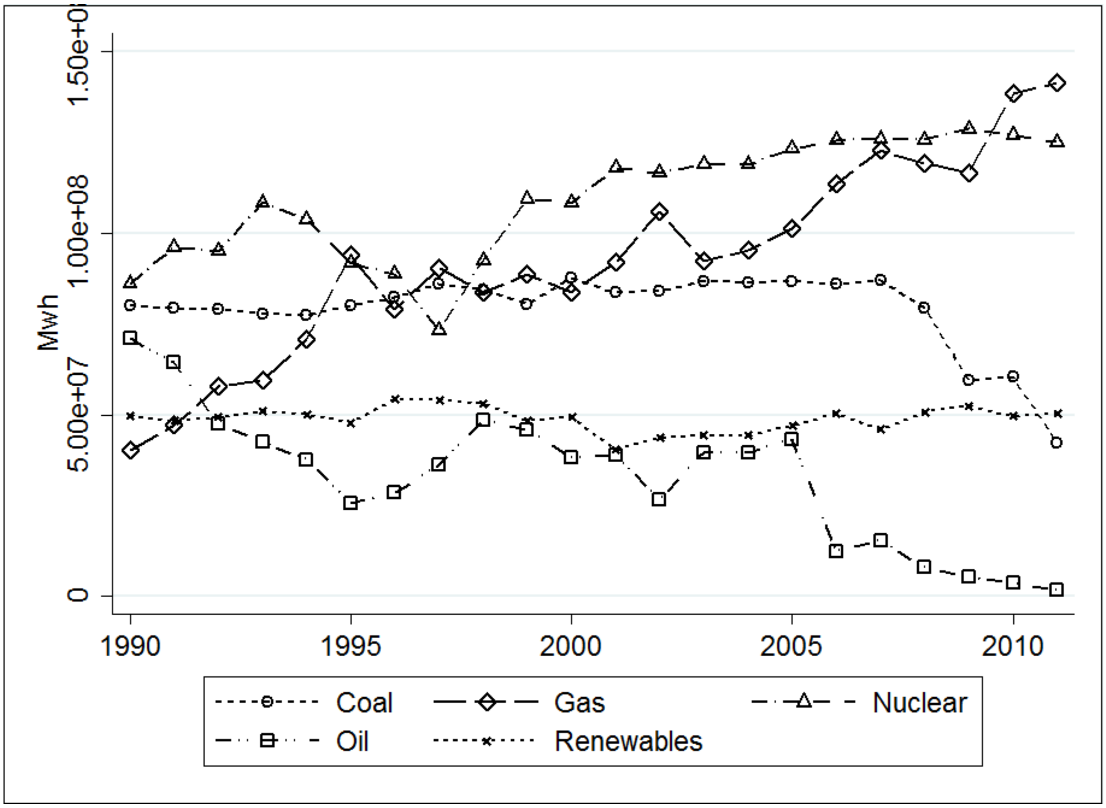

Figure 5. Electricity Generation by Source, RGGI States: 1990-2011

Source: US EIA (2013: Annual Power Generation Data by State, summed for RGGI states)

Complementary Policies

The exogenous shifts in emissions could also be due to policies that complement the RGGI cap-and-trade program, such as renewable portfolio standards (RPS), which exist in all of the 10 original RGGI states.[3] An RPS requires a certain portion of state power to come from renewable non-emitting sources and thereby creates the kind of baseline emissions reduction and MAC curve shifts depicted in Figure 1. Additionally, the RGGI program, apart from its emissions cap, contains complementary measures aimed at reducing emissions, such as the use of RGGI auction revenues for energy efficiency purposes (Hibbard et al. 2011). Federal Clean Air Act regulations for air pollutants such as SO_2, NOx, and mercury all impose regulatory requirements on coal-powered generation that favor substitution to viable alternatives such as natural gas, nuclear power, and renewables.

[3] The RPS is voluntary in Vermont.

Empirical Analysis

Relevant Literature

Some policy organizations release data on RGGI emissions and provide opinions on the causes of the emissions trends (e.g, Environment Northeast 2011), but to our knowledge there is no published research that statistically estimates RGGI programmatic effects versus other effects on emissions reductions.

One study with a similar ambition to estimate a cap-and-trade program's effect on emissions was performed for the European Union Emissions Trading Scheme (EU ETS) by Ellerman and Buchner (2008). They analyze emissions data before and after introduction of Phase I of the EU ETS from 2005 to 2007 to gauge how much of the observed decline in the region's emissions could be attributed to the program and how much to secular trends in emissions determinants such as weather, energy markets, and improvements in energy efficiency and emissions intensity. They use a mix of quantitative and qualitative analysis of emissions data to develop different proxies for the counterfactual emissions that would have occurred without the ETS and estimate that the program decreased emissions from as much as 8 percent to as little as 0.5 percent across the continent.

Our analysis departs from Ellerman and Buchner by using panel econometric methods to estimate emissions as a function of a range of policy, market, and environmental variables, which allows us to estimate the size and significance of individual factors contributing to the emissions decline before and after the RGGI program took effect.

A paper by Chevallier (2011) seeks to econometrically estimate the relationship between macroeconomic and energy market factors and EU ETS carbon prices using a Markov-Switching VAR model. It finds strong links between the factors and the prices, but Chevallier's ambition was not to quantify emissions reduction attribution, as is ours here.

Empirical Strategy

Our empirical strategy is to first develop a three-stage econometric model of electricity generation at the state level. We then use this econometric model to simulate baseline emissions based on observed data as well as a variety of counterfactual scenarios that remove particular policies or observed market shocks.

Data and Econometric Model

In the first stage, we estimate the demand for state-level electricity generation as a function of own price and demand shifters such as potential energy macroeconomic variables, weather variables, and policy variables. The first stage is estimated as equation 1.

$$c_{it} = X_{it}\beta + \mu_i + \varepsilon_{it} \qquad [1]$$

where c_{it} is the detrended electricity capacity utilization factor for state i in year t, and X_{it} includes the detrended electricity price, the detrended unemployment rate, population-weighted heating and cooling degree days (measures of weather-induced heating and cooling demand), the level of the state RPS, and a dummy for whether the state is under the RGGI program. The RGGI program uses some of its auction revenues for energy efficiency expenditures within the region (Hilliard et al. 2011), which could shift power demand. We do not observe these expenditures directly. Instead we assume they are homogenous across RGGI states, and we use the RGGI dummy variable to capture its effects on demand. A state-level fixed effect is captured by μ_i; ε_{it} is an iid unobservable.

The second-stage estimates derived power demand by generation fuel type, conditional on own and cross-fuel prices as well as total generation. This demand is estimated as equation 2.

$$f_{ijt} = Y_t\Theta + Z_{it}\Gamma + \nu_i + \delta_{ijt} \qquad [2]$$

where f_{ijt} is the detrended capacity utilization factor for generation using fossil fuel j in state i in year t. Fuel type j is coal, natural gas, or oil. For coal and gas generation, Y_t includes U.S. average coal prices and wellhead natural gas prices; Z_{it} includes the state capacity utilization factor (c_{it} above), the state RPS requirement, the detrended annual average carbon price for RGGI states, and a dummy variable for RGGI states in the RGGI compliance period.[4] A state-level fixed effect is captured by ν_i; δ_{ijt} is an iid unobservable.

Due to its high marginal cost, oil generation is now used sparingly in most states and typically only when demand is too high to be met with other generation sources. For oil generation, Y_t includes West Texas Intermediate (WTI) oil prices and wellhead natural gas prices; Z_{it} includes the same set of variables as for gas and coal plants.

The third-stage estimates CO_2 emissions as a function of generation from fossil fuels as in equation 3.

$$m_{it} = V_{it}\mathrm{K} + \xi_i + \sigma_{it} \qquad [3]$$

where m_{it} is the emissions from state i in year t, and Vit includes generation from coal, gas, and oil generation in state i in year t. A state-level fixed effect is captured by ξ_i; σ_{it} is an iid unobservable.

Our econometric model uses state-year data, largely from the U.S. Energy Information Administration (EIA 2013a–g). They provide state-year data on CO_2 emissions, total electricity generation, generation by fuel type, total generation capacity, generation capacity by fuel type,

[4] These prices may depart from the actual prices that generators face in a variety of ways. Coal generators often use long-term contracts with pre-specified prices as well as enter the spot market. Coal is primarily distributed by rail, so generators' actual procurement prices in the spot market will reflect both spot prices and rail prices. Natural gas generators make more use of spot markets. Gas is primarily distributed through pipeline, and thus there may be temporary local or regional shortages or gluts induced by limited pipeline capacity. Nonetheless, local gas prices are driven by broader spot prices, and thus spot prices are a reasonable measure. Furthermore national price indices ameliorate concerns that fuel prices would be endogenous to local production needs.

annual natural gas wellhead prices, and annual coal prices.[5] Annual price indices are from the Bureau of Economic Analysis (BEA); unemployment statistics are from the Bureau of Labor Statistics (BLS). RPS data are from the Database of State Incentives for Renewable Energy (DSIRE). Annual carbon prices are the average of clearing prices of carbon allowance auctions held in each year; auction clearing prices are available from RGGI. Finally, weather data are available from the National Climatic Data Center (NCDC). Summary statistics are presented in Table 1 for all 48 continental states and the 10 RGGI states.

TABLE 1

SUMMARY STATISTICS FOR DATA USED IN ESTIMATION

Variable	Units	48 States	RGGI States
Emissions	Million (metric) tons of CO2e	4.76 x 10^7	1.63 x 10^7
Total capacity utilization		0.467	0.433
Coal capacity utilization		0.594	0.454
Gas capacity utilization		0.283	0.529
Coal price	2005 $ per short ton	24.36	24.36
Gas price	2005 $ per thousand cubic feet	3.82	3.82
Unemployment rate	%	5.54	5.42
RPS level		0.0276	0.0277
Carbon price	2005 $ per ton CO2e	$0.0620	$0.298
Carbon price for 2009–2011	2005 $ per ton CO2e	$0.455	$2.18
Heating degree days		5103	6031
Cooling degree days		1125	634

Stationarity Tests

As is well known in econometrics, estimation based on nonstationary time series can lead to spurious results (Kennedy 2008). However, many series can be rendered stationary by removing a time trend. Fisher-style unit root tests (which run a unit root test on each panel and then jointly test the results) with Phillips-Perron tests with two lags on each group cannot reject the null of stationarity for total utilization rates (Choi 2001). However, the same tests do reject the null for the total, coal, gas, and oil utilization rates at the 1 percent level after detrending. Thus we use detrended data in our estimations.

Estimation Results

Estimation results are below in tables 2 through 4. We report both random and fixed effects estimates for each model. We will use fixed effects results for simulations as not all random effects models passed Hausman specification tests for random effects (Hausman 1978).

TABLE 2

ECONOMETRIC ESTIMATION RESULTS: TOTAL GENERATION

	Total Utilization Rate	
Electricity Price	-0.0336***	-0.00293**
	(0.00419)	(0.00119)
Unemployment	-0.0550***	-0.0106***
	(0.00125)	(0.00102)
Heating degree days	3.78e-06	-2.02e-07
	(4.74e-06)	(1.47e-06)
Cooling degree days	1.19e-5	-8.19e-07
	(1.11e-5)	(3.82e-06)
RPS	-0.0104	-0.0758
	(0.0550)	(0.0545)
RGGI program effect	0.0797***	0.0318***
	(0.0127)	(0.0107)
Fixed effects	Y	N
R-squared	0.02	0.11

Note: Total utilization rate results. Standard errors in parentheses.
* = 10, ** = 5%, *** = 1% confidence interval.

Most of the econometric estimates comport with theoretical expectations on sign. For instance, in the generation demand equation (Table 3), own-price effects are negative, higher unemployment reduces demand, and weather variables have expected effects (the more cooling and heating degree days in a state/year, the more power demand), though these effects are only marginally significant statistically. The RGGI program variable appears to have a positive effect on total utilization rate, which is somewhat surprising given the energy efficiency expenditures associated with the program. However, additional econometric analyses not reported in detail here suggest that there has been a modest decline in the scale of generation capacity under RGGI. This decline reduces both the numerator and denominator of the total utilization rate, resulting in a theoretically ambiguous sign. Analyses that estimate the level of total generation on the basis of a similar set of covariates (interacted with population to control for state size) yield more intuitive point estimates and qualitatively similar counterfactual simulation results.

TABLE 3

ECONOMETRIC ESTIMATES: GENERATION FUEL SOURCE DEMAND

	Coal Utilization Rate		Gas Utilization Rate		Oil Utilization Rate	
Coal price	-0.00326***	-0.00343***	0.0107**	0.0105**		
	(0.000596)	(0.000582)	(0.00500)	(0.00488)		
Gas price	0.0178***	0.0182***	-0.0187	-0.0178	0.0508***	0.0508***
	(0.00194)	(0.00189)	(0.0162)	(0.0158	(0.0191)	(0.0185)
Oil price					-0.00750***	-0.00749***
					(0.00189)	(0.00185)
Carbon price	-.0.00602	--0.00222	-0.0822	-0.0732	-0.0409	-0.0412
	(0.0200)	(0.0195)	(0.168)	(0.164)	(0.189)	(0.183)
Total util. rate	0.267***	0.265***	0.204	0.200	0.909**	0.909***
	(0.0465)	(0.0455)	(0.391)	(0.382)	(0.423)	(0.414)
RPS	-1.01***	-1.02***	0.625	0.588	-0.0889	-0.0875
	(0.0804)	(0.0784)	(0.675)	(0.657)	(0.760)	(0.739)
RGGI program effect	-0.0700	-0.0652	-0.052	-0.0401	0.0975	0.0971
	(0.0428)	(0.420)	(0.360)	(0.352)	(0.405)	(0.396)
Fixed effects	Y	N	Y	N	Y	N
R-squared	0.38	0.38	0.01	0.1	0.03	0.03

Coal, gas, and oil utilization rate results. Standard errors are in parentheses.
* = 10, ** = 5%, *** = 1% confidence interval.

The generation fuel source demand equations (Table 4) also comport largely with expectations: Own price effects are negative, and cross-price effects with competing fuels are positive. Individual fuel source utilization varies more strongly with total utilization for base load power such as coal than for gas, which often is utilized to hit peak demand. Coal utilization is lower in proportion to a state's RPS requirements. On the contrary, the impact of an RPS on oil generation is near zero. This finding makes sense as oil generation is primarily used to meet very high demand. The effects of RPS on gas generation are statistically insignificant and somewhat ambiguous given the direct competition and renewables on one hand yet differences in the use of each for base and peak load on the other. Carbon prices reduce fossil generation, but the effects are small and statistically insignificant because the prices are low, for reasons discussed above. The emissions equation estimates (Table 4) line up perfectly with expectation; coal and oil have more than double the emissions impact of gas.

TABLE 4

ECONOMETRIC ESTIMATION RESULTS: EMISSIONS

Coal generation	0.980***	0.989***
Gas generation	(0.00876)	(0.00739)
	0.394***	0.430***
	(0.00616)	(0.00601)
Oil generation	0.841***	0.897***
	(0.0223)	(0.0233)
Fixed effects	Y	N
R-squared	0.98	0.99

These results could raise concern about a lack of precision in some point estimates. However, estimates that we would expect to have the biggest impact—price elasticities, for example—are quite precise. Similarly, the impact of an RPS is indistinguishable from unity on coal, implying that renewables almost entirely substitute for coal base load. This result is both precise and reassuring given that coal has the greatest emissions per unit of generation.

Results of Simulation Exercise for Emissions Attribution

Our model simulation scenarios (detailed in Table 5) allow us to attribute the effect of different policies and market shocks by taking the difference between each scenario's emissions and baseline emissions.

TABLE 5

MODEL STIMULATION SCENARIOS

Scenario Number	Scenario Name	Description
0	Baseline	Uses observed data to simulate outcomes of interest.
1	Full counterfactual	Replace natural gas prices from 2009–2011 with those that existed in 2008 , replace unemployment rates from 2007–2011 remained with 2007 levels, setRGGI program effect and price effect to zero, set RPS variable to zero
2	Historical gas prices	Replace natural gas prices from 2009–2011 with 2008 levels
3	No RGGI	Set RGGI program effect and price effect to zero
4	No RPS	Set RPS variable to zero
5	No RGGI program effect	No RGGI program effect
6	No RGGI price effect	No RGGI price effect

For each simulation, we calculate the simulated statewide capacity utilization factor and fuel-specific capacity factors on the basis of counterfactual data, as defined in Table 6. The resulting equations are identical to equations 1 and 2 except that they omit the unobservable error term and add back in the time trend **θ**.

$$c_{it} = X_{it}\beta + \theta^{c}t + \mu_i \qquad [1']$$

$$f_{ijt} = Y_t\Theta + Z_{it}\Gamma + \theta^{f}t + \nu_i \qquad [2']$$

We then calculate the generation level of each fuel by multiplying the capacity factor times the capacity (measured in megawatt hours) times the number of hours in a year (8,760 or 8,784 for leap years) and use the result to simulate the emissions on the basis of equation 3.

$$m_{it} = V_{it}\mathrm{K} + \xi_i \qquad [3']$$

In each case, the coefficients are those estimated and reported in tables 2 through 4. Simulations were developed for all “lower 48” states, data for which were used for the econometric estimation, but given our policy focus, most simulation results reported here are for RGGI states only.

Figure 6 shows total RGGI state aggregate power sector emissions for each scenario over time; 95 percent confidence intervals are shaded. Panel A shows the simulated baseline; panel B, the full counterfactual scenario; panel C, the no recession scenario; panel D, the historic gas price scenario; panel E, the no RGGI scenario; panel F, the no RPS scenario; panel G, the no RGGI program effect scenario; and panel H, the no RGGI price effect scenario.

The RGGI program commenced in 2009 and continues through 2011, our last data year. In our "full counterfactual" scenario, emissions across the 2009–2011 period remained near their mid-2000s (pre-RGGI) peak. The simulations suggest that much of the decline is attributable to RGGI program effects, even after controlling for other factors such as the recession, natural gas prices, and RPS. Emissions declined much less in the "no RGGI" scenario than under the baseline. However, we cannot strongly distinguish the RGGI carbon price effect from a RGGI programmatic effect as reflected in the broad confidence intervals for the program and price effects but the relatively narrow confidence interval for the joint effect. Emissions under our "historic gas prices" scenario were also higher, suggesting that reduced natural gas prices did play a role in reducing emissions.

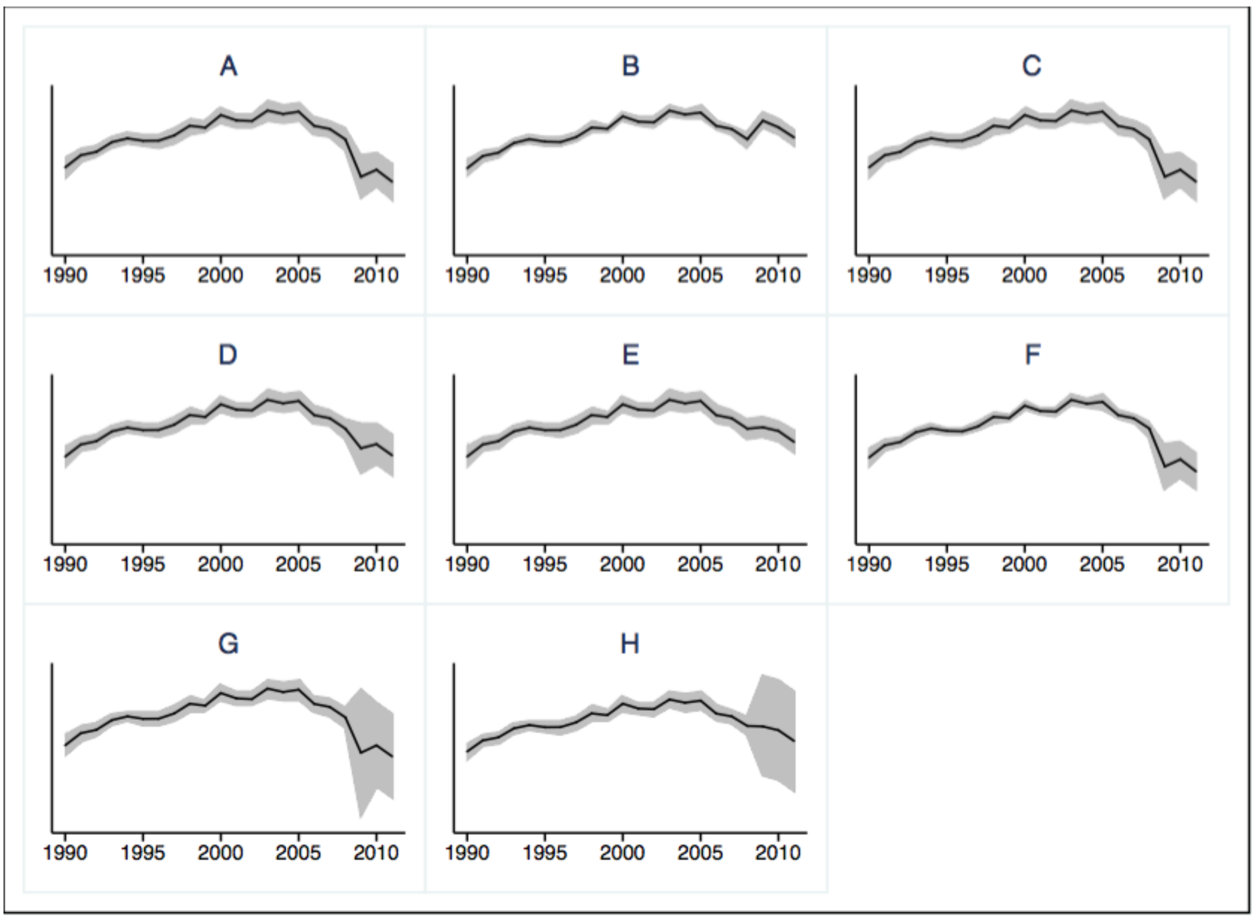

Figure 6. Simulated RGGI Emissions Across Scenarios

Figure 7 shows a t-test for the difference between the simulated emissions and baseline emissions for each scenario, along with a horizontal line at 1.96 representing the standard 5 precent confidence level. Panel A shows the full counterfactual scenario; panel B, the no recession scenario; panel C, the historic gas price scenario; panel D, the no RGGI scenario; panel E, the no RPS scenario; panel E, the no RGGI program effect scenario; and panel F, the no RGGI price effect scenario. Emissions in our "full counterfactual" and "no RGGI" scenarios were statistically distinct from the baseline, showing that the collective influence of RGGI, natural gas prices, RPA, and the economy led to a statistically significant decline in emissions in the region, as did the isolated effect of the RGGI program alone, all else equal.
The impact of the recession alone on emissions was both economically modest and statistically insignificant. This impact reflects the low elasticity of total generation (total utilization rate) with respect to our macroeconomic indicator, state unemployment rate.

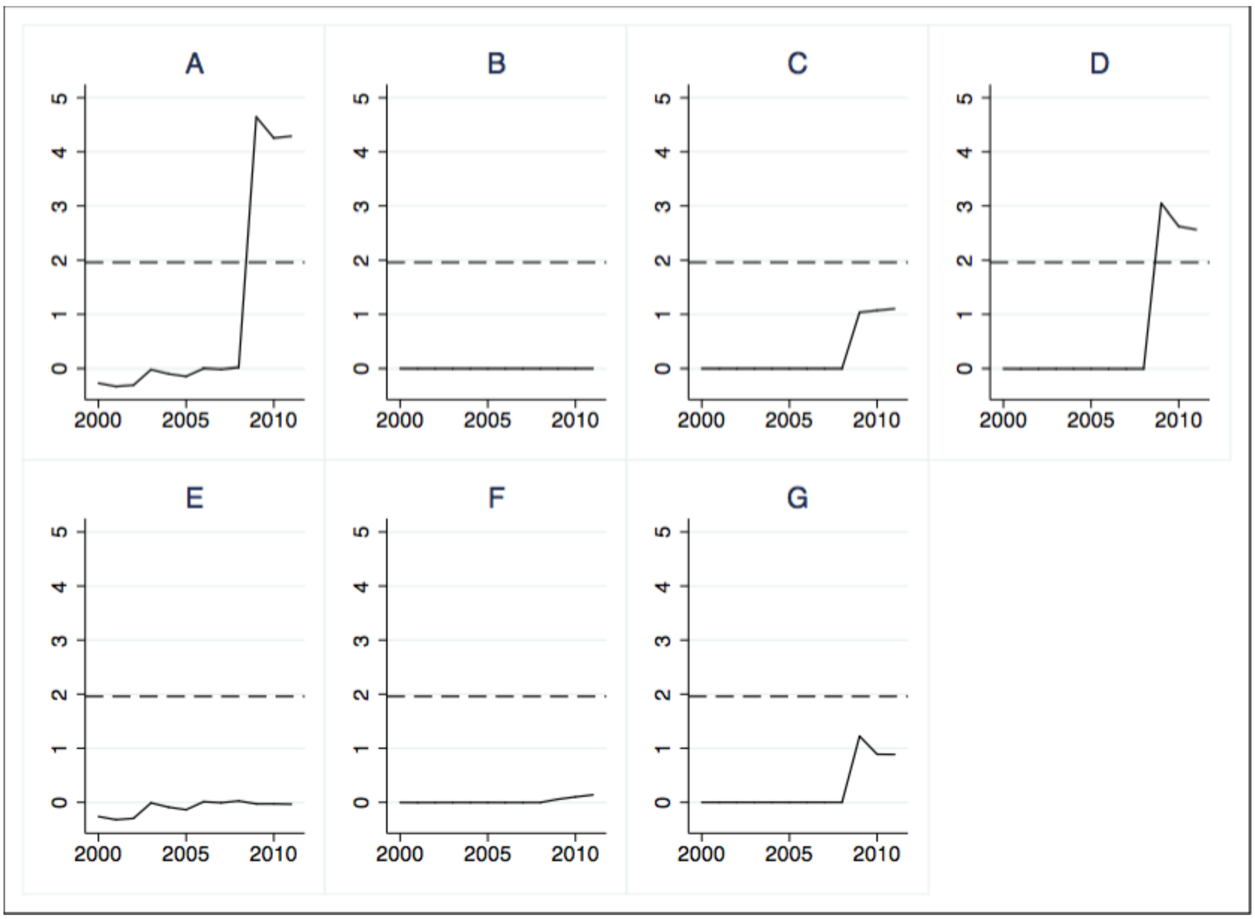

Figure 7. T-tests of RGGI Emissions vs Baseline Across Scenarios

Note: horizontal line at 1.96 (5% confidence threshold)

Table 6 summarizes the attribution of emissions effects in 2009–11. For each scenario, it shows the average percentage difference between emissions under that scenario and baseline emissions for both the RGGI region and the entire United States. For the all-U.S. simulations, emissions would be approximately 9 percent higher under the full counterfactual. The major determining factor nationally is the natural gas price/fuel switching phenomenon, accounting for 7 of the 9 percentage points. The recession was a relatively minor factor. The RGGI program effect, though regionally focused, does register nationally; almost 2 percent of the national emissions decline is attributed to it. Within the RGGI region, the total emissions effect is quite large, suggesting that emissions would be almost two-thirds higher if the full counterfactual prevailed. This finding is quantitatively in line with the nearly 40 percent drop in observed emissions. Most of the reduction in emissions can be attributed to the RGGI program, although the dramatic decrease in gas prices also played a major role. The effect of the recession was neither economically substantial nor statistically significant. Interestingly, the dramatic decrease in gas prices had a bigger absolute percentage effect on emissions in the RGGI region than nationally, perhaps because the RGGI region is so close to Pennsylvania, a center of the recent expansion in gas production.

TABLE 6

EMISSIONS EFFECT BY SCENARIO: 2009–11 AVERAGE (PERCENT)

Scenario	Percentage change in RGGI emissions	Percentage change in U.S. emissions
Full counterfactual	65.5%	9.2%
No recession	1.4%	1.1%
Historic gas prices	23.5%	7.3%
No RGGI	41.2%	1.9%
No RPS	-0.6%	-1.1%
No RGGI program effect	-1.7%	-0.1%
No RGGI price effect	42.9%	2.0%

Testing for Evidence of Leakage

One possible explanation for the decrease in RGGI region emissions is that generation and emissions have shifted to non-RGGI states. If the shift is due to the policy, it is called "leakage." Studies of leakage of subnational policies in other contexts have shown that leakage rates can reach up to 70 percent and that regulations placing compliance costs on producers in a market-based setting (such as generators in electricity markets) are particularly likely to lead to leakage (Goulder 2012; Bushnell 2008). Evidence for the existence of leakage from RGGI is mixed; Shawhan et al. (2014) use *ex ante* simulation methods and find that leakage would occur, but RGGI (2013) found no *ex post* statistical evidence of leakage.

Natural gas production increased dramatically over our study period to due technological advances in production technology (fracking). This increase was particularly dramatic in Pennsylvania. Although not a RGGI state, Pennsylvania shares a border with RGGI states to the north, east, and south.[6]

[6] New Jersey remained in the program from 2009 to 2011, the time period covered by this study.

The increase in gas production led to lower gas prices and switches from coal to gas generation. Coal generation decreased significantly and substantially more in RGGI states than in other nearby states. This finding suggests that gas-based electricity may have been preferentially exported to RGGI states, perhaps due to the RGGI program's regulation of emissions within its borders. However, preferential exports could also be affected by transmission limits, electricity price differentials, or other factors. Additional research might differentiate these factors.

To test for leakage, we consider three sets of potential "leaker" states. The first set is composed of the member states of PJM, an electric power regional transmission organization (RTO) that coordinates the distribution of wholesale electricity in all or parts of 13 eastern U.S. states and the District of Columbia, which are not in RGGI (some PJM states are in RGGI, some are not). The second set is made up of a subset of PJM states: Ohio, Pennsylvania, West Virginia, and Virginia. These states are geographically closer to RGGI states than other PJM members and thus potentially would have more tightly linked electricity grids. The third set is Pennsylvania. For each of these potential leaker sets, we re-estimate the econometric equations for coal and gas [Eq 2], adding in dummy variables, which are 1 for potential leaker states during the RGGI compliance period. These variables are detrended in keeping with the rest of the estimation. All specifications in Table 7 include fixed effects and omit the carbon price so as to more clearly compare treatment effects.

TABLE 7

ESTIMATION OF LEAKAGE EFFECTS IN STATES ADJACENT TO RGGI

	COAL UTILIZATION RATE			GAS UTILIZATION RATE		
	PJM as Leaker	Some PJM as Leaker	PA as Leaker	PJM as Leaker	Some PJM as Leaker	PA as Leaker
Coal price	-0.00335***	-0.00317***	-0.00336***	0.0110**	0.0111**	0.0107**
	(0.000611)	(0.0006)	(0.000597)	(0.00514)	(0.00505)	(0.00502)
Gas price	0.0179***	0.0170***	0.0178***	-0.0196	-0.0201	-0.0182
	(0.00202)	(0.00200)	(0.00194)	(0.170)	(0.0165)	(0.0164)
Total utilization rate	0.269***	0.267***	0.266***	0.207	0.202	0.199
	(0.464)	(0.0464)	(0.0465)	(0.391)	(0.391)	(0.391)
RPS	-1.00***	-1.00***	-1.01***	0.633	0.637	0.615
	(0.0806)	(0.0804)	(0.0807)	(0.678)	(0.677)	(0.679)

RGGI dummy	-0.0892***	-0.0940***	-0.0884***	-0.242*	-0.245*	-0.232*
	(0.169)	(0.166)	(0.0166)	(0.142)	(0.140)	(0.140)
Leaker dummy	0.00540	-0.0405*	0.0531	-0.0256	-0.0889	0.152
	(0.169)	(0.235)	(0.0456)	(0.142)	(0.198)	(0.383)
R-squared	0.38	0.38	0.38	0.01	0.01	0.01
Wald test – leaker dummy different than RGGI dummy	Y at 1%	Y at 5%	Y at 1%	N	N	N

For all three specifications of leakers, the coal utilization rate declined more in RGGI states than in the leakers, and the difference was statistically significant. Although the gas utilization rate also declined more in RGGI states, the difference between that rate and the rate in the leakers was not statistically significant. These results are consistent with RGGI-induced leakage effects. A more robust assessment of the nature and specific attribution of these effects is beyond the scope of this paper but would make an excellent research topic.

We make a back-of-the-envelope calculation of the potential emissions implications of this leakage by assuming that the entire difference between the utilization rates inside and outside RGGI were due to leakage. We do this for coal and gas and for coal alone. These calculations should be viewed as illustrative only, especially given the lack of statistical precision associated with the gas generation leakage effect.

Caveats aside, the “PJM as leaker” specifications indicate that if the entire difference between the RGGI effect and the leaker effect were indeed due to leakage, the coal leakage would constitute 9.2 percent of RGGI region emissions over the 2009–2011 period, whereas the coal and gas leakage combined would constitute 39.5 percent of emissions. This latter leakage estimate is roughly the size of the entire reduction in emissions under the RGGI program. However, the gas calculation, in particular, may produce a higher-than-plausible leakage in the short term; pipeline capacity constraints have reportedly limited gas shipments into parts of the RGGI region, and, again, the difference in point estimates is not statistically significant (EIA 2014).

To summarize, policy leakage is plausible, consistent with observed generation and emissions outcomes, and is potentially of economically significant magnitude. However, a more detailed analysis of leakage effects across regions is necessary to draw more robust conclusions and policy inferences.

Conclusions and Policy Implications

The end of the first decade of the 21st century provided an unusual time window to discern how different policy, technology, and market factors influenced greenhouse gas emissions in the United States. During this period, policies were emerging at different levels of government to directly reduce greenhouse gases or indirectly reduce them through complementary measures such as renewable portfolio standards and energy efficiency programs. At the same time, technological breakthroughs in hydraulic fracturing and horizontal drilling led to a surge of new accessible natural gas reserves, lower prices, and expanded use, especially in the northeastern United States, where this study is focused. The switch on the margin from higher-emitting coal to lower-emitting gas has reduced the emissions intensity of electricity production. Yet another contributor to the decline in emissions was the economic recession of the late 2000s—the deepest recession in the United States since the 1930s.

Many researchers and industry observers agree that all of these factors—policies, markets, and macroeconomic conditions—contributed to post–2008 U.S. emissions reductions, but there is little to no empirical evidence pointing to the individual contribution of each of these factors. Finding this evidence is particularly important for the 10 northeastern states that comprised the Regional Greenhouse Gas Initiative (RGGI) that formed during the middle of the last decade and went into full effect in 2009. The RGGI states experienced a far more dramatic proportional decline in emissions in the electric power sector (the nation's largest source of emissions) than the rest of the United States. This decline could be attributable to the RGGI program, which directly regulated GHG emissions from electric power; other policies; the fact that RGGI states were at or near the epicenter of the natural gas resource surge; or asymmetric effects of the economic recession on the RGGI region.

This study attempts to attribute emissions reductions to these factors by linking a conceptual framework of the cap-and-trade program developed under RGGI to an econometric model of the U.S. electric power sector that estimates state-level power generation demand, fuel mix, and emissions. We use the econometric model to develop counterfactual simulations to attribute, ex post, the factors driving emissions trends. For the RGGI states, we find the following:

- **Power sector emissions would be more than 60 percent higher by 2011** in RGGI states were it not for the combination of policy, natural gas market, and macroeconomic factors that emerged in the late 2000s.
- **The economic recession for only about 1 percent of the emissions decline.**
- **Natural gas markets were responsible for more than one-third of the region's emissions decline.** They induced substitution in the generation mix from higher-emitting fossil fuels to natural gas.
- Once the factors just referenced are controlled for, **the RGGI program appears to be the dominant factor in the emissions decline.** It is difficult to statistically separate the effects of the RGGI price from other aspects of the program, such as the use of RGGI auction proceeds for energy efficiency and other low-carbon investments. However, the

low RGGI price and the appearance of regional effects once the program was announced but before trading started suggest that complementary program effects may be the key factor. Additional research is needed to further explore the causes.

- **Some or all of the reduction in RGGI emissions may be countered by generation and emissions leakage to surrounding states.** Our econometric analysis of spillover effects in states adjacent to the RGGI states that are part of the same regional transmission organization suggests that these non-RGGI states may have picked up generation, especially from coal, that was diverted because of the RGGI program. Back-of-the-envelope calculations show that this effect could be large relative to the entire reduction in emissions under the RGGI program.

Taken together, these results have important policy implications. First, there appears to be substantial room for emissions reduction in electric power generation, which accounts for about one-third of national emissions in the United States. This emissions reduction potential has implications for U.S. efforts to meet domestic and international global climate commitments. Second, a tightly targeted cap-and-trade program like RGGI can be effective at reducing emissions through a combination of the emissions trading elements and other programmatic elements that incentivize energy efficiency and reduced carbon intensity of electric power. This finding has implications for the state of California, which in 2013 instituted a multi-sector cap-and-trade program to help meet its GHG reductions under state law and which has attempted to link its carbon market to a carbon market in the Canadian province of Quebec.

The results also strongly point to the critical role that natural gas discoveries have played in reducing emissions. Natural gas, even before its recent surge in availability, has been viewed as a bridge to a lower-carbon future, given its lower-than-coal-and-oil carbon content per unit of energy. Now the questions are will demand sharply increase and raise its price, putting a brake on continued expansion and emission reductions on the margin? Will water quality and other environmental and safety concerns place limits on fracking and natural gas production? And how will even more ambitious targets for GHG reductions (e.g., more than 50 percent by mid-century) direct responses beyond natural gas, which is still a carbon emitter?
Our results suggest that regional strategies can be effective in cutting emissions within a region but that one consequence of improvements in one region targeted by policies could be shifting of problems to other regions. Because greenhouse gases are a global pollutant, more comprehensive coverage is necessary for effective policy.

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