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Cap and Trade and CO2 Emissions: Was the U.S. Regional Greenhouse Gas Initiative (RGGI) Effective?

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Was the U.S. Regional Greenhouse Gas Initiative (RGGI) Effective?

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Abstract

The Regional Greenhouse Gas Initiative (RGGI), the first cap and trade program for CO_2 emissions in the United States, began in 2009 with 10 states: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. The goal of the program was to reduce regional CO_2 emissions from the electricity sector. We employ the Synthetic Control Method (SCM) for comparative case study to estimate the impact of RGGI on CO_2 emissions. Our estimates show that while RGGI did not decrease overall CO_2 emissions from the electricity sector it led to a decline in CO_2 emissions from coal-generated electricity. We also find some evidence of policy leakage with neighboring states.

Keywords: Cap and Trade; CO_2 Emissions; Regional Greenhouse Gas Initiative (RGGI); Synthetic Control Method (SCM)
JEL classification: Q54, Q4, Q48, H7

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I. Introduction

In the United States, an interest in a national cap and trade policy peaked in 2009, when the U.S. House of Representatives passed the American Clean Energy and Security Act, but no bill passed in the Senate and the legislation faltered (C2ES 2018).[2] Around the same time, however, states in the Northeast joined a regional cap and trade market. This initiative, the Regional Greenhouse Gas Initiative (RGGI), began in 2009 with 10 states: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont (U.S. EPA, 2016). New Jersey, however, quit the program in 2011 (Murray and Maniloff, 2015).[3]

The goal of the RGGI is to reduce CO_2 emissions from the electricity sector (RGGI Elements, 2018). According to the RGGI organization, as of 2016, member states had reduced electricity sector CO_2 emissions by more than 45 percent since 2005 (RGGI Investment, 2016). On its own, this is an impressive statistic and seems to point to the success of the cap and trade initiative. However, the program did not begin until 2009, so any drop prior to its implementation is difficult to attribute to the policy change. In addition, the Great Recession of 2008-09, led to a drop in CO_2 emissions across the region. Figure 1 shows that both RGGI and non-RGGI states experienced a significant drop in emissions between 2007 and 2009, prior to the implementation of RGGI.[4]

There is empirical work that provides evidence of RGGI's success at reducing emissions. Murray and Maniloff (2015), using a state-level difference-in-difference approach, find that electricity sector emissions across the region would have been 24

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[2] At the national level, there were policies that regulated CO_2 emissions beginning in 2007, when the Supreme Court rule that the pollutants regulated under the Clean Air Act could include greenhouse gas (GHG) emissions.
[3] In 2018, New Jersey decided to rejoin RGGI (Plumer, 2018).
[4] We further explore the potential influence of the Great Recession on our findings in Results V.3.

percent higher without the implementation of RGGI (Murray and Maniloff 2015). Kim and Kim (2016) expand on Murray and Maniloff (2015) and find a reduction in CO_2 emissions due to a shift from coal to natural gas in electricity generation. They conclude that due to the RGGI, the share of natural gas in the RGGI region increased by 10-15 percent.

There is also a significant research studying different aspects of the first cap and trade program for CO_2 emissions, the European Union Environmental Trading Scheme (EU-ETS).These include research examining permit price (Koch et al 2016; Hintermann, Peterson, and Rickels 2015; Medina, Pardo and Pascual 2014; Aatola, Ollikainen, and Toppinen 2013; Hintermann 2011; Hintermann 2010), whether the EU-ETS has led to emissions reductions (Bel and Joseph 2015; Anderson and Di Maria 2011; Ellerman, Denny and Buchner 2008), and analyzing other market impacts of the policy (Hintermann 2016; Rogge, Schneider and Hoffmann 2011).

In this paper, we employ the Synthetic Control Method (SCM) for comparative case studies (Abadie and Gardeazabal 2003, Abadie, Diamond and Hainmueller 2010) to estimate the impact of the 2009 RGGI over the period 1990-2015. We analyze the entire RGGI region (excluding New Jersey) as well as subsets of the region to determine if there have been differential impacts on CO_2 emissions within the RGGI region. In particluar, we examine New England (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont), New York and Maryland-Delaware separately. The management of the electricity grid in the RGGI region is divided into three separate balancing authorities: ISO New England, New York ISO, and PJM, which includes the Maryland-Delaware region (EIA 2016). Although electricity can be transmitted across the Eastern Interconnection, the regional operation of the grid by distinct balancing authorities may lead to differences in the influence of the RGGI program. This could lead to differences in the fuel mix that is used to generate electricity within each balancing region.[5] Since the Maryland-Delaware region is a small part of the larger PJM balancing region, they may be more strongly influenced by other states in their balancing region that are not part of the RGGI. In addition, because New Jersey left the RGGI, the Maryland-Delaware region is a geographically isolated region among the RGGI states. Huang and Zhou (2019) examine the impact of RGGI only on the PJM region; they find that there is a decrease in coal generation in the Maryland-Delaware region.

In addition to overall CO_2 emissions and total emissions from the electricity sector, we also examine emissions by fuel type.[6] Specifically, we analyze emissions from coal and natural gas generated electricity separately.[7] Coal and natural gas are the dominant fuels used in electricity generation in the United States (EIA State 2018), and the RGGI program targets electricity sector emissions rather than total emissions (RGGI Elements 2018). This allows us to build on the findings from Fell and Maniloff (2018) and examine possible fuel switching. Because natural gas generated electricity produces less CO_2 emissions, increases in natural gas generated emissions or decreases in coal-generated emissions would support the Fell and Maniloff (2018) findings.[8]

Our estimates show that RGGI did not reduce CO_2 emissions from the electricity sector. However, we find that RGGI led to a decline in CO_2 emissions from coal-generated

[5] Balancing authorities manage the transmission of electricity on the grid. They are responsible for ensuring that supply and demand of electricity are balanced continuously (EIA System 2016).

[6] The RGGI cap and trade program includes mandates only for electricity generating firms. However, the policy also used the revenue from sales of permits to invest in programs to reduce overall CO_2 emissions in the RGGI region (RGG Investment, 2016).

[7] Other fuels used for electricity generation include renewables and nuclear energy. Generation from these sources does not emit CO_2 emissions.

[8] Natural gas generation produces only a fraction of the pollutants per unit of electricity generation and approximately half of the greenhouse gases (GHGs) that are produced by coal (Fischer 2014).

electricity. Over the period 2010-2015, we find that CO_2 emissions from coal-generated electricity declined by an annual average of 44 percent in the RGGI region; within the RGGI region, the impact was most robust in New England and Maryland-Delaware regions where CO_2 emissions from coal-generated electricity declined by an annual average of 57 and 29 percent, respectively. Our estimated impacts of RGGI for New York, while slightly less robust than those of New England and Maryland-Delaware, are qualitatively the same as New England and Maryland-Delaware.

While our findings are notably different from those of Murray and Maniloff (2015) we do not feel that our findings are directly comparable to those of Murray and Maniloff (2015). First, we use SCM as opposed to the state-level difference-in-difference approach used in Murray and Maniloff (2015). Traditional regression based difference-in-difference models estimate an average treatment effect across all RGGI states. SCM allows us to construct separate counterfactuals for the New England, New York and Maryland-Delaware regions, which, in turn, allows for the possibility of heterogeneous impacts of RGGI within the RGGI region.[9] Second, we use 6 years of post-RGGI periods as opposed to 3 years of post-RGGI periods covered in Murray and Maniloff (2015). Finally, by examining emissions by fuel type, we are able to determine how the RGGI policy has differentially influenced different types of electricity generation.

Unlike Murray and Maniloff (2015), Kim and Kim (2016) use SCM. We have concerns about the implementation of SCM in Kim and Kim (2016). In SCM, a placebo study is used to draw statistical inference. The SCM generates a synthetic outcome for a treatment region, which is the counterfactual in the absence of the intervention (RGGI). A

[9] See Keele, Malhotra, and McCubbins (2013) for a discussion of treatment heterogeneity. See Guettabi and Munasib (2017) for a discussion of treatment heterogeneity in the context of U.S. states.

measure of post-intervention difference between the actual and the synthetic provides the SCM estimate of the impact. In the placebo study, the same method is applied to each control unit (U.S. states) *as if* it also had implemented RGGI; then the placebo impact of the unit is calculated. At this point, the estimated effect of the actual treated unit can be compared against the placebo effects on the control units. If all the placebo effects are smaller than the actual effect on the treated unit, it is evidence of statistical significance (Abadie, Diamond and Hainmueller 2010, Maguire and Munasib 2016, Ehrich et al. 2018). Kim and Kim (2016) find that the placebo effects of two of their control units are larger than the actual effect of their treated unit, i.e., the treated unit is ranked third and two control units that did not implement RGGI exhibited a stronger effect on emissions from their placebo policy than the RGGI region. The authors interpret this as a significant finding, which is not the common practice in determining statistical significance in SCM (Abadie, Diamond and Hainmueller 2010).[10]

In addition, we have concerns about the interpretation of the results. Their outcome variable, gas share, is defined as the annual net generation from natural gas divided by the sum of annual net generation of natural gas and coal. RGGI is designed to decrease CO_2 emissions and, if effective, would be expected to lead to increases in natural gas generated electricity and/or decreases in coal-generated electricity because it has lower emissions than coal. Either of these changes would lead to an increase in the gas share variable. However, the interpretation in the paper is that the variable only measures switching

[10] On page 334, Kim and Kim (2016) mention, "Because Fig. 11 includes 31 control states, the probability of estimating a gap of the magnitude of the gap for RGGI under a random permutation of the intervention in our data is 6.5% (=2/31)." However, if we were to follow Abadie, Diamond and Hainmueller (2010), we would calculate a value 9.4% (=3/32), where 3 is the rank of the treated state and 32 is the total number of units in the analysis, and interpret it as the following: there is a 9.4% probability that a placebo effect will be just as large as or larger than the RGGI treatment effect (see, for example, Ehrich et al. 2017, among others).

between coal, a high emissions fuel, and natural gas, a low emissions fuel. In fact, a successful RGGI could lead to lower coal-generated emissions, or increased natural gas generated emissions, or both. It is not possible to discern which of these effects is being measured by the gas share variable. In other words, it is not a measure only of coal to natural gas switching. All other fuels used for electricity generation in the United States have lower CO_2 emissions than coal, so a decline in coal generation does not necessarily indicate coal to natural gas switching. Huang and Zhou (2019) also examine coal to natural gas switching for the Maryland-Delaware region only, they do not find evidence of fuel switching, instead finding only an increase in coal generation.

Linn and Muehlenbachs (2018) examine the role of low natural gas prices on coal to natural gas switching, electricity prices, and emissions, for the period 2001-2012, in the United States. They find significant regional heterogeneity in the impact of low natural gas prices. For much of the United States, they find that a decrease in natural gas prices significantly increased natural gas generation and a switch from coal to natural gas. However, in the Northeast Power Coordinating Council (NPCC) region, which includes ISO New England and the New York ISO, natural gas prices did not have a significant effect on the amount of natural gas generation and did not lead to coal to natural gas switching. These heterogeneous impacts are highly correlated with the share of natural gas generation prior to the implementation of RGGI (p. 15, Table 4). The authors find that the regions, such as the NPCC, with a large share of natural gas generation had a subsequently low increase in the amount of natural gas generation, and they did not have a significant switch from coal to natural gas because they already had high natural gas generation. Other regions that had a large increase in natural gas generation relative to coal had a small share of natural gas generation prior to the decline in natural gas prices. As mentioned above, these heterogeneities existed prior to the RGGI implementation and are well accounted for in the construction of the synthetic RGGI. We incorporated natural gas capacity or generation in our set of predictors for pre-intervention matching (natural gas to total capacity in the main specification and natural gas to total generation in the alternative specification).

II. Background

II.1. RGGI

RGGI, which began in January of 2009, is the first cap and trade program for CO_2 emissions in the United States. The cap for CO_2 emissions is set for the entire region and enforced by each state. Utilities included in the cap and trade program include all 164 utilities that produce a minimum of 25 MWh of electricity annually from fossil fuels (Ramseur 2017, p.2). As is standard with cap and trade markets, the cap has been adjusted downward every year or two years since the program began in 2009 (RGGI Elements, 2018). Similar to the implementation of the EU-ETS, the RGGI cap was not binding for several years after implementation. In 2014, states agreed to a 45 percent decline in the cap in order to better match emissions levels and the cap became binding (Ramseur 2017, p.9). Prior to 2014, although the emissions cap was not binding, there was a price floor of approximately $2 for emissions certificates, the permit price did not exceed the price floor between September 2008 and January 2013, so the price floor was binding (EIA RGGI, 2014).[11]

[11] In January of 2013, RGGI announced the cap reduction that would take place in 2014. This led to an increase in the permit price above the price floor in expectation of the binding cap. Firms in the RGGI are able to bank permits purchased in the current period for future periods.

II.2. The U.S. Electricity Market

The U.S. electricity market has undergone a significant transition in the last 20 years. From a sector dominated by coal-generated electricity, the electricity sector has shifted in two directions, towards renewable generation and towards the use of natural gas. In the 1990s, coal generated electricity comprised greater than 50 percent of total electricity generation (EIA Coal 2016). In 2016, natural gas supplanted coal as the dominant source of electricity generation, the share of natural gas was 34 percent while coal's share was reduced to 30 percent. Renewable generation continued its steady growth to reach 15 percent of total generation (EIA 2016)[12,13]

Several factors are driving the substitution away from coal. First, there are state level policies, such as Renewable Portfolio Standards (RPS) and federal and state Production Tax Credits (PTC) that have encouraged the adoption of renewable generation. Second, there have been lower natural gas prices due to the widespread implementation of hydraulic fracturing technology in the U.S. in the mid-2000s. From a peak of $9.26 per Mcf in 2008, natural gas electric power prices had declined 68 percent in real terms by 2016 (EIA NG 2017).[14] While coal remains a less expensive fuel source for electricity generation, the significant drop in natural gas prices has reduced the gap in prices significantly (AEO 2018, p. 90-92).

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[12] Renewable generation includes generation from commercial scale hydropower, biomass, biofuels, wind, geothermal, and solar.

[13] States in the RGGI region use nuclear generation, which produces zero CO_2 emissions. The share of electricity generation from nuclear capacity has remained steady in the United States at approximately 20 percent since approximately 1990 and no new nuclear capacity has been added in the region in the last 30 years (WNA 2018).

[14] Using the 2009 BEA GDP Implicit price deflator, real natural gas electric power prices have gone from $9.19 per Mcf in 2008 to $2.99 per Mcf in 2016.

III. Data

We collected the data for our outcome variables from the EIA.[15] Our SCM specification includes 39 donor pool states. The outcome variables are total CO_2 emissions, CO_2 emissions from electricity sector, CO_2 emissions from coal-generated electricity, and CO_2 emissions from natural gas generated electricity. We use per capita emissions for all of our analyses in order to normalize the measures across distinct regions and states. For robustness, we also examine per capita renewable generation. Policies that increase the cost of CO_2 emissions may lead to increases in renewable generation, which produces no CO_2 emissions.

The other energy data, including electricity generation and price, generating capacity, number of customers, etc., were also collected from the EIA. The remaining data were obtained from the U.S. Bureau of Economic Analysis (BEA) and the U.S. Census Bureau. Table 1 presents a summary description of all the variables used in the analysis.

A descriptive analysis of the EIA data shows that the RGGI region produced an annual average of 5.71 percent of total U.S. CO_2 emissions from electricity generation between 1990 and 2015. The average declined after the implementation of RGGI, from 6.26 percent prior to 2009 to 4.12 percent after 2009. Figure 2 provides information on the transition from coal to natural gas generated electricity in the U.S. as a whole and in the RGGI region from 1990 through 2015. The figure shows that, like the rest of the nation, prior to the 2009 RGGI, the share of coal generation in RGGI states was larger than that of natural gas generation. The coal share was approximately half for the RGGI states as

[15] CO_2 emissions are not directly measured, rather the Energy Information Association (EIA) collects data on generation by fuel type and constructs emissions measures based on the predicted emissions for each fuel. Coal and natural gas are the primary sources of electricity sector emissions because they are the two dominant fuels used in electricity generation. Nuclear and renewable generation produce zero emissions.

compared to the national average even prior to RGGI, however. In addition, unlike the national average, the natural gas share overtook, and dwarfed, that of coal in the RGGI region beginning in 2004. For the nation, coal share did not exceed the natural gas share during the sample period. While natural gas prices dropped due to hydraulic fracturing, the RGGI states increased the share of natural gas generation prior to the RGGI at a much faster rate than the U.S. as a whole. This may indicate that the states in the RGGI region selected into the CO_2 cap and trade policy because of their lower cost of reducing emissions. As stated previously, natural gas generation produces approximately half of the emissions that are produced by coal.

IV. Empirical Specification

The Synthetic Control Method (SCM) is used in our analyses primarily because no single state constitutes an appropriate control group for the RGGI region or its sub-regions. SCM analysis is feasible when one or more states exposed to an intervention can be compared to other states that were not exposed to the same intervention.[16] For this reason, we have excluded California. California passed a climate plan in 2006 that led to the adoption of their cap and trade program in 2013. Although the cap and trade implementation date was subsequent to the RGGI implementation by several years, the state was in the process of implementing CO_2 reducing policies prior to 2013.

Following Abadie and Gardeazabal (2003) and Abadie, Diamond and Hainmueller (2010), we use SCM to construct a comparison (synthetic) state/region that is a

[16] The set of state year characteristics that we use as predictors in our SCM analyses include total net generation, coal generation, natural gas generation, and renewable generation. These measures capture the effects of state level renewable energy policies in the RGGI region and in the control states.

combination of the donor pool (unexposed/control states) with a data-driven procedure that calculates 'optimal' weights that are assigned to each state in the donor pool based on *pre-intervention* characteristics (Abadie and Gardeazabal 2003; Abadie, Diamond and Hainmueller, 2010). The variables that we used for the pre-intervention matching are included in Table 1.[17] The 'optimal' weights are calculated to compute the strongest pre-intervention match for the outcome variable between the treated region and the donor pool (Abadie and Gardeazabal 2003; Abadie, Diamond and Hainmueller 2010). Our pre-intervention period extends from 1990 through 2008, providing a very long period from which to construct the synthetic control. Abadie, Diamond, and Hainmueller (2010) demonstrate that with a long pre-intervention matching on outcomes and characteristics, a synthetic control also matches on time-varying unobservables.

Once an optimal weighting vector is obtained, the post-intervention synthetic control is constructed by calculating the weighted average of the outcome variable for the donor pool. The post-intervention values of the synthetic control serve as our counterfactual outcome variable for the treatment unit. We calculate the ratio of post- to pre-intervention root mean square prediction error (RMSPE) that puts the magnitude of post intervention gap (between the actual and the synthetic outcome) in the context of the pre-intervention fit (between the actual and the synthetic outcome): the larger the ratio the greater is the impact of the intervention (Abadie, Diamond and Hainmueller 2010). The post-intervention gap between the actual outcome and the synthetic outcome, therefore, captures the impact of the intervention.

[17] Pre-intervention CO_2 emissions outcomes at two-year intervals are included in the set of pre-intervention characteristics. Results are robust to inclusion of other combinations of pre-intervention outcomes.

To test the significance of this estimate, we apply the permutations or randomization test as suggested by Bertrand et al. (2004), Buchmueller et al. (2011), Abadie, Diamond and Hainmueller (2010) and Bohn et al. (2014). Specifically, for each state in the donor pool, we estimate the impact of a fictitious (placebo) RGGI intervention in 2009. The distribution of these placebo estimates then provides the equivalent of a sampling distribution for the estimate for the treated region (Bohn et al. 2014, Munasib and Rickman 2015). Note that this answers the question, how often would we obtain an effect of RGGI of a magnitude as large as that of the treatment region if we had chosen a state/region at random, which is the fundamental question of inference (Buchmueller et al. 2011; Abadie, Diamond and Hainmueller 2010; Bertrand et al. 2004).

We calculate three statistics. First, the rank of the post- pre-RMSPE ratio; a rank of 1 is considered significant. For the treatment effect to be significant, no placebo effect should be larger than the effect estimated for the treated state/region. The p-value of the post- to pre-RMSPE ratio of the treated region is calculated using the distribution described above. And finally, following Abadie, Diamond and Hainmueller (2010), we divide the rank of the post-pre MSPE ratio by one plus the size of the donor pool, this provides the probability of obtaining a post-pre MSPE ratio as large as the treated region if one were to assign the intervention at random in the data (the so called 'donor probability').

V. Results

V.1. SCM Estimates of the Impact of RGGI on per capita CO_2 Emissions: Main Findings

We find that the RGGI initiative led to a decline in CO_2 emissions from coal-generated electricity. We do not find a significant impact of the RGGI cap and trade program on the following three CO_2 emissions measures in any of the four treated regions (all RGGI states, New England, New York or Maryland-Delaware): overall CO_2 emissions, total electricity sector CO_2 emissions, and CO_2 emissions from natural gas generated electricity.

Table 2 presents the SCM estimates of the impact of RGGI on CO_2 emissions for the four treated regions. Columns 1 and 5 contain results for overall CO_2 emissions, columns 2 and 6 for CO_2 emissions from electricity generation, columns 3 and 7 for CO_2 emissions from coal generation, and columns 4 and 8 for CO_2 emissions from natural gas generation. We find that the post- pre-intervention RMSPE rank for CO_2 emissions from coal is 1 for all four treatment regions. The donor probability is 3 percent with a one percent level of significance. The New York result, however, is not robust. In subsections V.2 and V.3 below, we present a series of robustness tests where the estimated impacts on New York are not statistically significant.

Table 2 shows that Idaho, Florida, Colorado, Pennsylvania, Texas, Missouri and Oklahoma have the largest weights in the construction of the synthetic control for the RGGI region. Idaho, Florida, Texas, Illinois, Pennsylvania and Colorado have the largest weights in the synthetic for New England while Colorado, Hawaii, Idaho, Georgia, Illinois, Alaska, Louisiana, Kansas and Missouri have the largest weights in the synthetic for Maryland-Delaware. In SCM analysis, there is a concern that the inclusion of neighboring states, such as Pennsylvania, in the donor pool may lead to an underestimate of the effects of the policy. This is true in the case that the bordering states are affected by the policy and due to imports and exports of electricity across balancing regions; this may affect our analysis of RGGI. In order to address this issue, in Table 8 below, we exclude all states that border the RGGI region; our findings are robust to this specification.

We estimate that the RGGI initiative led to a decline in CO_2 emissions from coal-generated electricity by an annual average of 44, 57, 60 and 29 percent in the RGGI, New England, New York, and Maryland-Delaware regions, respectively. These reductions amount to 26, 9, 10 and 8 million metric tons of CO_2 emissions reductions in the RGGI, New England, New York, and Maryland-Delaware regions, respectively. These are economically significant results; twenty six million metric tons of CO_2 emissions are equivalent to 6 percent of the total CO_2 emissions in the RGGI region in 2009.

Key findings of the impact of RGGI are graphically presented in Figures 3 and 4.[18] Figures 3 shows the SCM estimates of the impact of RGGI on total CO_2 emissions from electricity generation for each treatment region. In each figure, we observe a close fit between the actual and the synthetic pre-intervention and a divergence between the actual and the synthetic post-intervention. However, as we see from columns 2 and 6 of Table 2, the post- pre-intervention RMSPE ratios have ranks that are not significant and have large donor probabilities; 28, 38, 48 and 15 percent for the RGGI, New England, New York, and Maryland-Delaware regions, respectively.

Figure 4 includes the estimates of the impact of RGGI on CO_2 emissions from coal-generated electricity in each treatment region. Again, we observe a close pre-intervention fit between actual and synthetic outcomes but now, post-intervention, we observe large gaps between the actual and synthetic. The post-intervention gaps are not only visually large; they are also statistically significant as shown in columns 3 and 7 of Table 2. The RMSPE ratio rank is 1 in each region and the donor probabilities are 0.03.

V.2. Robustness

[18] Additional figures are available upon request.

The estimates in Table 2 (the main estimates) are generated using the following set of predictors for pre-intervention matching: coal- to total generation, nature gas- to total capacity, total per capita net generation, percent of population 25 plus with college, per capita commercial sales, per capita personal income and population share of residential customers. Panel A of Table 5 presents the pre-intervention matches between the characteristics of the synthetic and the actual units.

Table 3 presents the same SCM estimates but uses an alternative set of predictors: natural gas to total electricity generation ratio, coal- to total electricity capacity ratio, percent homeowners, per capita real industrial revenue ('000 2005 $), per capita total sales (MWh), per capita total foreign direct investment (thousands 2005 $), per capita personal income ('000 2005 USD), population share of residential customers (%) and population share of industrial customers (%). Panel B of Table 5 presents the pre-intervention matches between the characteristics of the synthetic and the actual units for these alternative set of predictors. In Table 5, for each SCM estimate, we find that a large majority of the predictors achieve close matches.

In the alternative set of predictors, we included among others population share of industrial customers (panel B of Table 5). The RGGI states are quite different from the donor pool in terms of this predictor. We find that our estimated impacts of the intervention on CO_2 emissions from coal-generated electricity for RGGI, New England and Maryland-Delaware remain statistically significant and hence robust to this perturbation. The impact for New York, however, is no longer statistically significant.

It may be argued that the gap between the synthetic and the treatment unit is caused by the synthetic's inability to replicate the treatment's post-intervention outcome.

To address this concern we use placebo tests using a fictitious RGGI year as a falsification test (Mideksa 2013, Abadie et al. 2014). We assign a placebo RGGI intervention in 2002 rather than 2009. Table 4 presents these 'time placebo' tests using the period 1990-2008. The results in Table 4 indicate that there is no statistically significant post-intervention gap.

V.3. The Great Recession

The implementation of the RGGI policy in 2009 coincided with the Great Recession in 2008-09. As stated previously, the emissions data presented in Figure 1 shows that both RGGI and non-RGGI states experienced a significant drop in emissions. Using the SCM method, we are able to construct an appropriate counterfactual that accounts for both time-invariant and time-varying heterogeneities. This produces a synthetic treated unit that is expected to be similar to the actual treated unit and account for homogeneous effects of the Great Recession on treated and synthetic regions. However, we cannot rule out the possibility that Great Recession may have had heterogeneous effects on the RGGI region and the states used to construct the synthetics. For example, suppose that the synthetic region was constructed entirely out of states like North Dakota, which may have recovered from the recession more quickly due to the economic gains from fracking in the state that may have led to a strong increase in electricity demand leading to an increase in overall emissions in the donor pool. In this scenario, the synthetic estimates from SCM would not only measure the effect of the RGGI policy but also the heterogeneous effects of the Great Recession. Therefore, we examined to what extent, the impact of the Great Recession varied between the treated and the donor pool states.

We have constructed pre- and post-intervention per capita personal income growth rates for the treated units (RGGI region and sub-regions) and their respective donor pools in Table 6. These growth rates demonstrate that the pre- and post-intervention synthetic growth rates are very similar to the actual growth rates in the region. For example, the average growth rate in the RGGI region is 4.1 percent pre-intervention and 2.8 percent post-intervention. The pre-intervention average growth rates for the synthetic RGGI regions range from 4.0 percent for total electricity emissions donor states to 4.2 percent for coal-generated electricity emissions donor states. The largest variation is for New York post-intervention; the actual average growth rate is 3.1 percent, while the post-intervention growth rates vary from 2.2 percent for coal-generated emissions to 2.9 percent for total electricity emissions donor states. The closeness of the post-intervention growth rates between the actual and their respective synthetics demonstrate the strength of the pre-intervention matching.

V.4. The Issue of Leakage

A significant research area for regional environmental policies such as RGGI is policy leakage. Leakage occurs when firms are able to avoid regulation by shifting production to unregulated neighboring regions (Fowlie 2009, p.1). There have been several papers that have examined issues of leakage in U.S. regional environmental regulations in general terms (Bushnell and Chen 2012; Fischer and Fox 2012; Fowlie 2009) as well as for those focusing specifically on California's cap and trade program (Caron, Rausch, and Winchester 2015; Fowlie 2009). There also are papers that focus on leakage in the RGGI region (Huang and Zhou 2019; Fell and Maniloff 2018; Lee and Melstrom 2018; Chen 2009).

In the case of RGGI, leakage could occur if electricity generators were able to produce electricity for the RGGI region without being subject to the RGGI cap and trade system, such as from a neighboring state. Fell and Maniloff (2018) argue that the RGGI policy has led to a decline in coal generation in RGGI states and a rise in natural gas generation in Pennsylvania and Ohio. Both of these states produce and transmit electricity to RGGI states but are not part of the RGGI region. Huang and Zhou (2019) find that leakage is a significant issue for the Maryland-Delaware region as well.

To address the issue of leakage, first we rerun our main estimates by excluding all the states bordering the RGGI region. If these states were affected by RGGI in any way, they could contaminate the donor pool. We run the same estimates that we presented in Table 2, except that we exclude Ohio, Pennsylvania, West Virginia and Virginia from the donor pool (Table 7). We find that the results are qualitatively the same and quantitatively similar to the results in Table 2.

To examine the leakage issue further, we have carried out SCM estimates of the impact of RGGI on electricity generation (total generation, generation from coal and generation from natural gas) in all four states bordering the RGGI states: Ohio, Pennsylvania, Virginia and West Virginia (Table 8). We find a statistically significant impact only in case of natural gas generation in Ohio; a doubling of electricity generation from natural gas that is 5 percent of total 2009 generation in Ohio and 2 percent of total 2009 generation in the RGGI region.

VII. Conclusion

The goal of the RGGI is to reduce CO_2 emissions from the electricity sector (RGGI Elements, 2018). Documentation in support of RGGI declares that, as of 2016, member states had reduced electricity sector CO_2 emissions by more than 45 percent since 2005 (RGGI Investment, 2016). This statistic does not necessarily capture the stand-alone effect of the RGGI program, which began in 2009, and confounds the effects of RGGI with other factors that may have led to a decline in emissions in the RGGI region. In our analysis, we are able to construct an appropriate counterfactual using SCM that accounts for both time-invariant and time-varying heterogeneities.

We find a modest contribution of the RGGI cap and trade on CO_2 reduction. It is important to note that the program did not have a binding cap until 2014; a similar procedure was followed with the EU-ETS. The rationale is that a non-binding cap allows for a learning period for market participants and often provides a politically feasible method of implementing the cap and trade program across a diverse set of actors. Our estimates examine only the 2010-2015 period following the start of the program, a period during which the cap was largely not binding. Therefore, the question of the long-term influence of the RGGI and the influence of a binding RGGI cap on CO_2 emissions reductions remains unanswered. It is also important to note that while we do not find evidence of large leakages from the neighboring states in the short run, however, the longer-term influence of leakage is left for future work.

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Figures

Figure 1: Electricity Sector CO_2 Emissions Levels

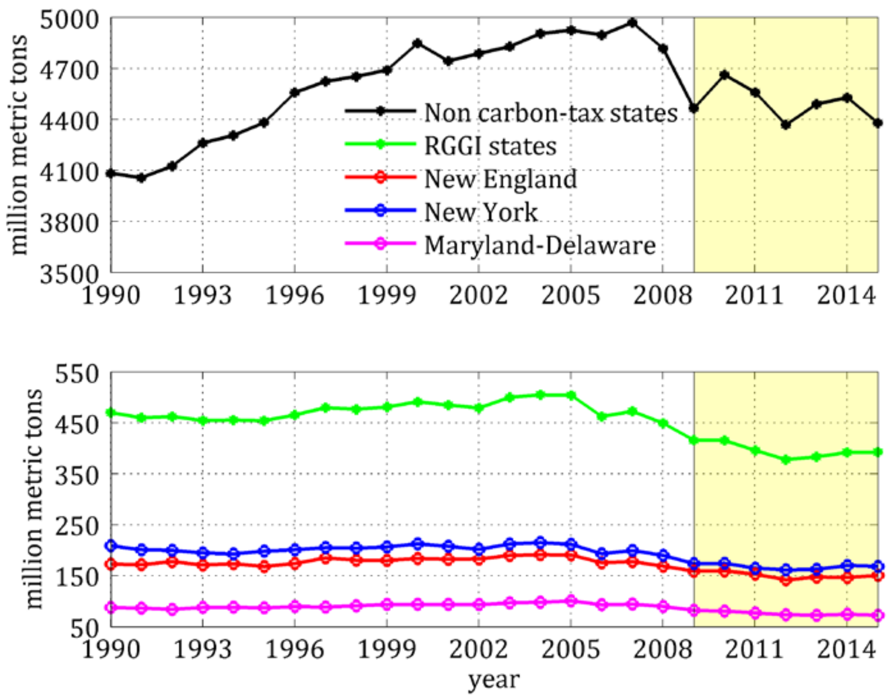


Figure 2: U.S. and RGGI Coal and NG Generation Share 1990-2015

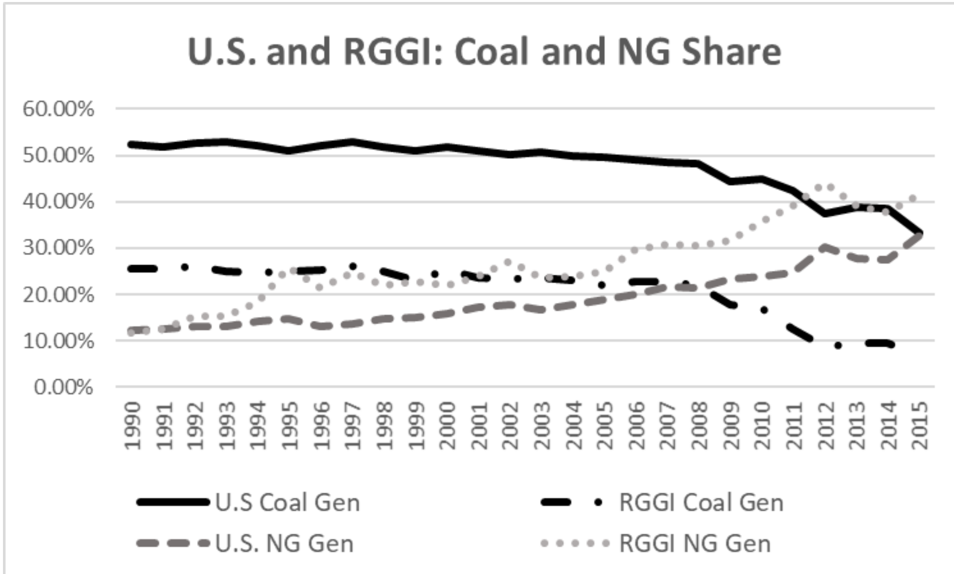


Figure 3: SCM Estimates of the Impact of Cap and Trade on Total Per Capita CO_2 Emissions from Electricity Generation

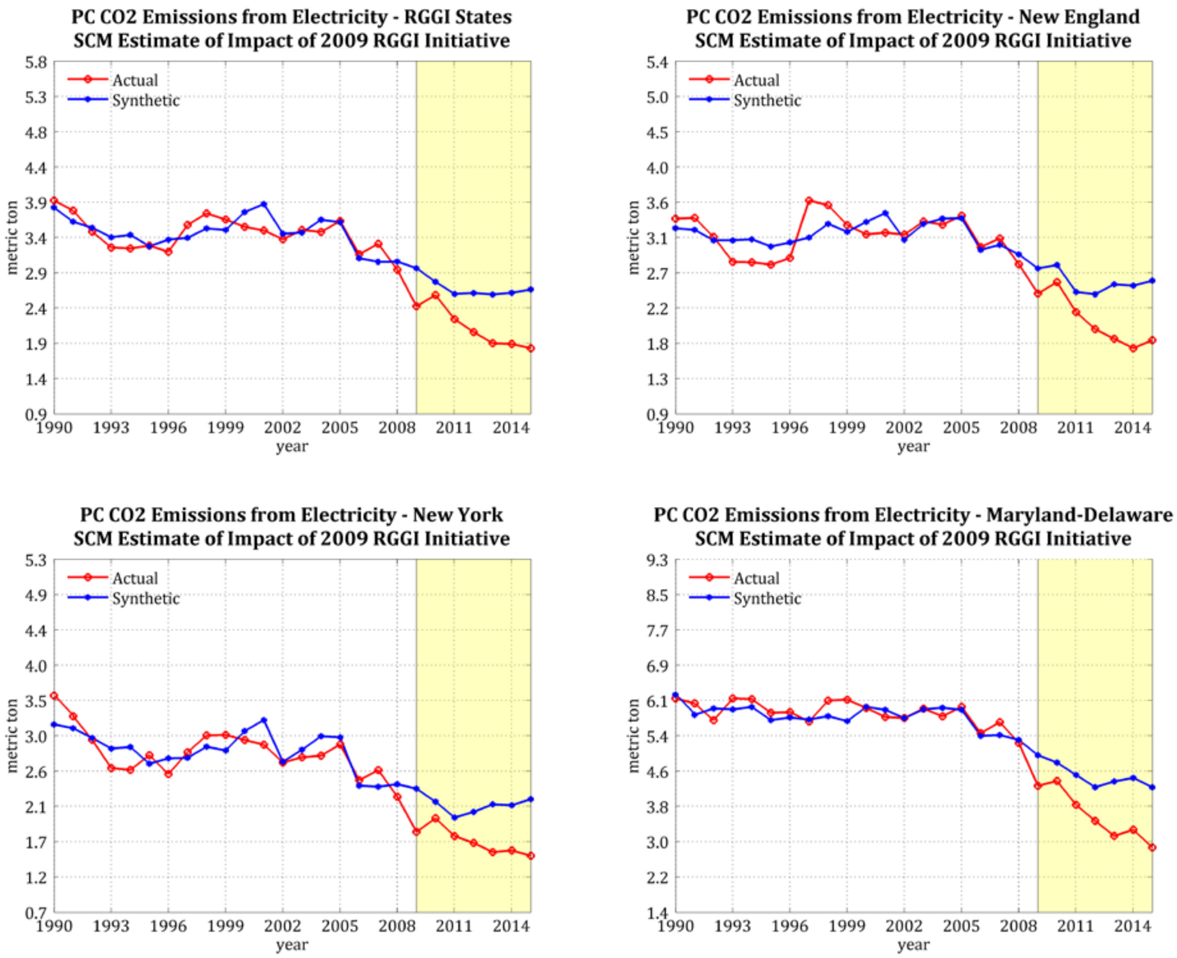


Figure 4: SCM Estimates of the Impact of Cap and Trade on Per Capita CO_2 Emissions from Coal Electricity Generation

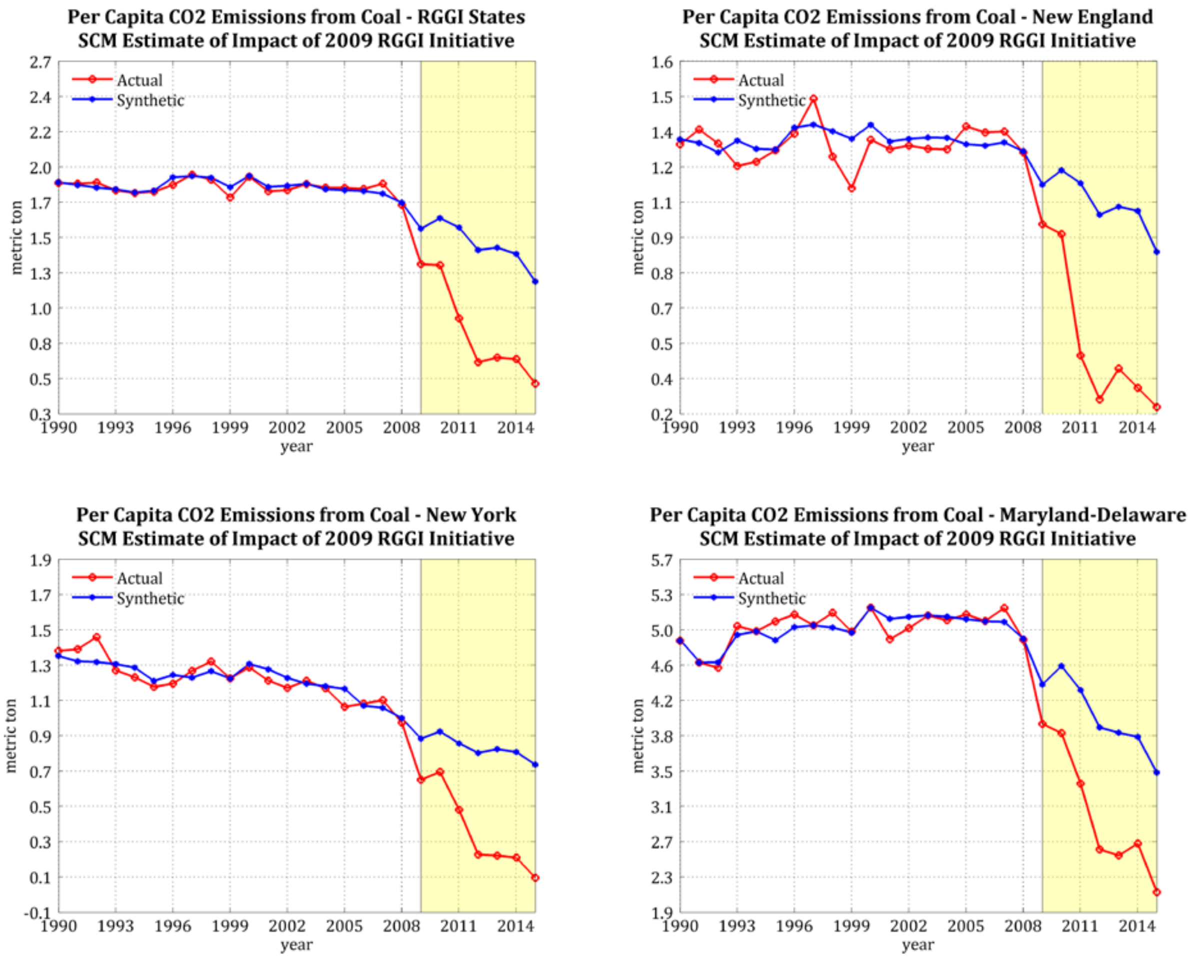
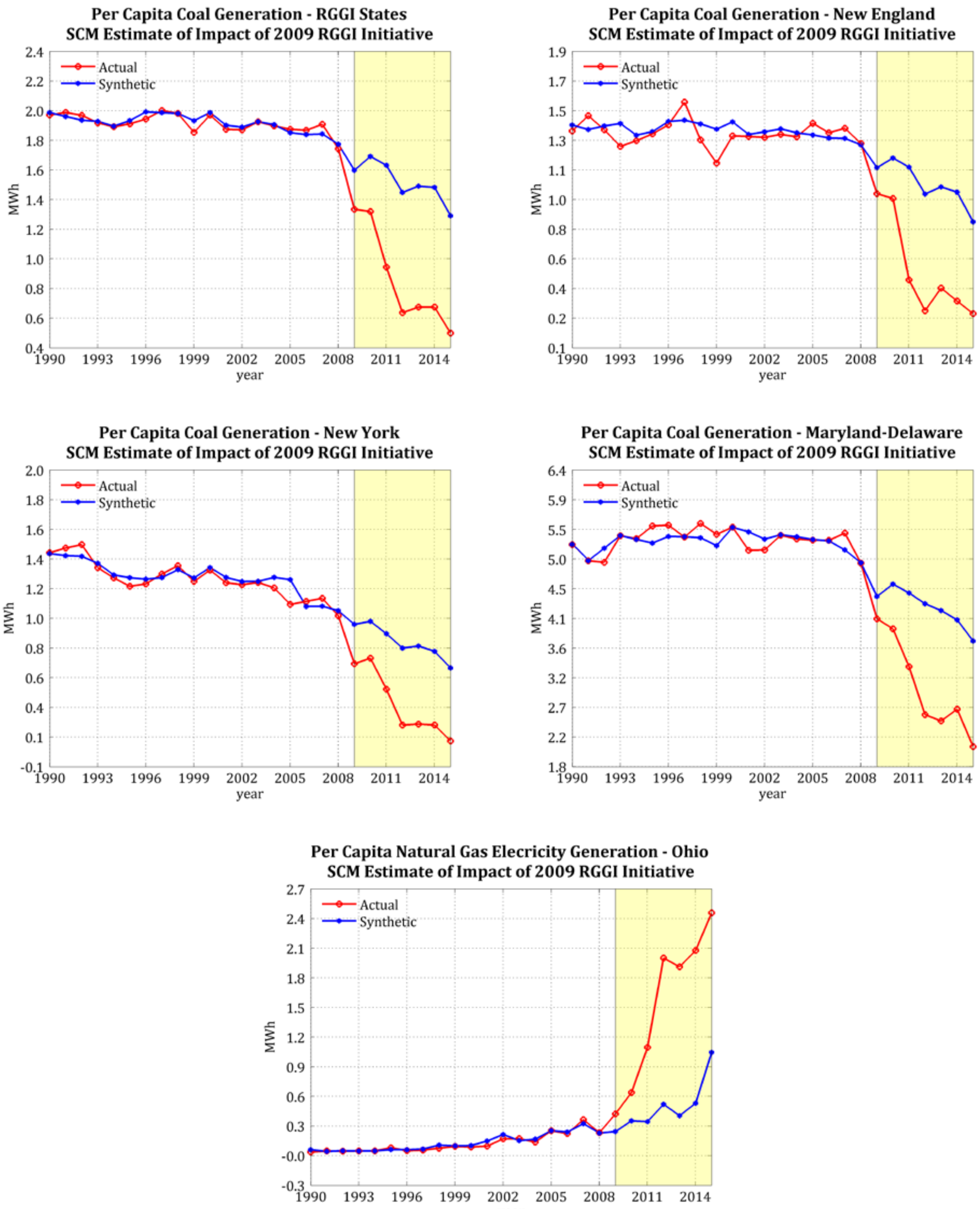


Figure 5: SCM Estimates of the Impact of Cap and Trade on Per Capita Coal Electricity Generation in RGGI States and Per Capita Natural Gas Electricity Generation in Ohio



Tables

Table 1: Summary Statistics

	39 Donor Pool States				Mean			
	mean	st. dev	min	max	RGGI	NE	NY	MD
Outcomes in metric tons (1990-2015)								
PC total CO_2 emissions (metric ton)	28.16	20.75	9.43	130.62	11.56	12.27	10.21	14.13
PC CO_2 emissions from electricity sector (metric ton)	12.85	14.37	0.00	90.67	3.07	2.87	2.51	5.26
PC CO_2 emissions - electricity from coal (metric ton)	11.70	14.73	0.00	90.47	1.57	1.10	0.98	4.45
PC CO_2 emissions - electricity from natural gas (metric ton)	0.88	1.15	0.00	6.05	0.94	1.07	1.03	0.36
PC hydroelectric generation (MWh)	1.80	3.34	0.00	18.36	0.92	0.56	1.40	0.30
PC coal electricity generation (MWh)	11.86	14.68	0.00	88.75	1.64	1.15	1.02	4.69
PC natural gas electricity Generation (MWh)	2.04	2.78	0.00	15.08	2.08	2.63	2.13	0.71
Predictors (1990-2008)								
Coal- to total electricity generation ratio	0.57	0.27	0.00	0.99	0.24	0.16	0.17	0.59
NG- to total electricity generation ratio	0.11	0.16	0.00	0.68	0.22	0.25	0.26	0.06
Coal- to total electricity capacity ratio	0.45	0.26	0.01	0.98	0.16	0.10	0.11	0.40
NG- to total electricity capacity ratio	0.22	0.20	0.00	0.77	0.28	0.25	0.34	0.17
PC total net electricity generation (MWh)	18.86	14.09	6.96	92.40	8.01	8.44	7.34	9.08
Percent homeowners	67.74	4.22	53.90	75.20	58.87	63.96	52.60	66.96
% population 25 plus with college	22.11	4.14	12.30	35.60	28.82	30.25	27.31	30.24
PC Real industrial revenue ('000 2005 $)	0.25	0.11	0.06	0.81	0.14	0.18	0.10	0.18
PC commercial sales (Megawatt-hours)	3.83	0.92	0.97	8.08	3.37	3.35	3.20	3.93
PC total Sales (Megawatt-hours)	13.66	3.47	7.30	30.57	8.35	8.30	7.35	11.61
PC total foreign direct investment ('000 2005 $)	4.89	7.88	0.68	52.64	3.12	3.05	3.47	2.73
PC personal income ('000 2005 USD)	29.43	4.85	18.15	45.19	37.67	38.11	37.47	37.25
Population share of residential customers (%)	41.22	3.30	28.42	48.48	38.06	41.40	35.64	37.98
Population share of industrial customers (%)	0.32	0.31	0.03	2.27	0.13	0.20	0.06	0.17

Note: (a) PC = per capita. RGGI = 9 of the 10 Regional Greenhouse Gas Initiative states which includes NE = New England, NY = New York, MD = Maryland-Delaware. New Jersey is excluded which quit RGGI in 2011. (b) Percent homeowners has only two data points. (c) The donor pool consists of 39 states, i.e., the 10 original RGGI states, California and the District of Columbia are excluded. CA passed a Climate Plan in 2006, cap and trade didn't start until 2013. Low carbon fuel standard started in 2011.

Table 2: SCM Estimates of the Impact of Cap and Trade on Per Capital CO_2 Emissions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	RGGI region				New England			
APEMR	0.02	0.04	0.01	0.06	0.03	0.05	0.04	0.13
Pre-int RMSPE	0.33	0.16	0.03	0.07	0.39	0.20	0.07	0.14
Estimated impact	-1.21	-0.55	-0.64	0.16	-0.69	-0.54	-0.60	0.22
RMSPE Rank	8	11	1	27	22	15	1	30
P-value	0.18	0.25	0.00	0.65	0.53	0.35	0.00	0.73
Donor probability	0.20	0.28	0.03	0.68	0.55	0.38	0.03	0.75
Donor pool weight								
Alaska	0.00	0.28	0.00	0.12	0.00	0.07	0.00	0.09
Colorado	0.00	0.00	0.06	0.00	0.00	0.00	0.02	0.83
Florida	0.00	0.00	0.11	0.05	0.35	0.20	0.09	0.08
Georgia	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
Hawaii	0.12	0.10	0.00	0.08	0.00	0.00	0.00	0.00
Idaho	0.69	0.49	0.73	0.00	0.36	0.59	0.78	0.00
Illinois	0.00	0.00	0.00	0.62	0.00	0.00	0.04	0.00
Missouri	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Nevada	0.00	0.13	0.00	0.13	0.00	0.07	0.00	0.00
North Carolina	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oklahoma	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Oregon	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00
Pennsylvania	0.00	0.00	0.05	0.00	0.00	0.00	0.03	0.00
Texas	0.00	0.00	0.03	0.00	0.00	0.00	0.05	0.00
Virginia	0.04	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Washington	0.03	0.00	0.00	0.00	0.10	0.00	0.00	0.00
	New York				Maryland-Delaware			
APEMR	0.05	0.06	0.04	0.10	0.01	0.03	0.01	0.31
Pre-int RMSPE	0.58	0.22	0.05	0.12	0.24	0.20	0.10	0.11
Estimated impact	-1.74	-0.52	-0.49	0.01	-1.20	-0.92	-1.17	-0.08
RMSPE Rank	12	19	1	40	2	6	1	36
P-value	0.28	0.45	0.00	0.98	0.03	0.13	0.00	0.88
Donor probability	0.30	0.48	0.03	1.00	0.05	0.15	0.03	0.90
Donor pool weight								
Alaska	0.00	0.04	0.03	0.00	0.00	0.00	0.06	0.00
Arizona	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
Colorado	0.00	0.00	0.10	0.00	0.00	0.00	0.28	0.00
Georgia	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00
Hawaii	0.00	0.19	0.00	0.38	0.22	0.22	0.25	0.00
Idaho	1.00	0.65	0.80	0.00	0.17	0.26	0.11	0.00
Illinois	0.00	0.00	0.00	0.13	0.00	0.00	0.08	0.54
Kansas	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Louisiana	0.00	0.00	0.00	0.13	0.00	0.00	0.05	0.00
Minnesota	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00
Missouri	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Nevada	0.00	0.12	0.02	0.05	0.13	0.10	0.00	0.00
New Mexico	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00
Oregon	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00
South Dakota	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
Utah	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
Virginia	0.00	0.00	0.05	0.00	0.20	0.00	0.00	0.46

Notes: (a) APEMR = Absolute prediction error to mean ratio, RMSPE = Root mean squared prediction error, Estimated impact is the post-intervention difference between actual and synthetic, RMSPE Rank = post- to pre-intervention RMSPE ratio. (b) Only donor pool units with weight>=0.01 are reported. (c) Columns 1 and 5: total CO_2 emissions; Columns 2 and 6: CO_2 emissions from total electricity generation; Columns 3 and 7: CO_2 emissions from coal generation; Columns 4 and 8: CO_2 emissions from natural gas generation.

Table 3: SCM Estimates of the Impact of Cap and Trade on Per Capita CO_2 Emissions (Alternative set of Predictors)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	RGGI region				New England			
APEMR	0.02	0.09	0.03	0.09	0.03	0.05	0.04	0.09
Pre-int RMSPE	0.33	0.36	0.07	0.10	0.37	0.20	0.07	0.11
Estimated impact	-1.21	-0.73	-0.81	0.19	-0.67	-0.56	-0.57	-0.38
RMSPE Rank	6	20	1	28	18	11	1	20
P-value	0.13	0.48	0.00	0.68	0.43	0.25	0.00	0.48
Donor probability	0.15	0.50	0.03	0.70	0.45	0.28	0.03	0.50
	New York				Maryland-Delaware			
APEMR	0.05	0.17	0.11	0.16	0.01	0.03	0.01	0.09
Pre-int RMSPE	0.58	0.54	0.16	0.20	0.24	0.18	0.11	0.04
Estimated impact	-1.74	-0.83	-0.59	0.23	-1.60	-1.12	-1.06	0.25
RMSPE Rank	9	26	13	36	2	4	1	14
P-value	0.20	0.63	0.30	0.88	0.03	0.08	0.00	0.33
Donor probability	0.23	0.65	0.33	0.90	0.05	0.10	0.03	0.35

Notes: (a) APEMR = Absolute prediction error to mean ratio, RMSPE = Root mean squared prediction error, Estimated impact is post-intervention difference between actual and synthetic, RMSPE Rank = post- to pre-intervention RMSPE ratio. (b) Columns 1 and 5: total CO_2 emissions; Columns 2 and 6: CO_2 emissions from total electricity generation; Columns 3 and 7: CO_2 emissions from coal generation; Columns 4 and 8: CO_2 emissions from natural gas generation.

Table 4: SCM Estimates of the Impact of Cap and Trade on Per Capita CO_2 Emissions – Time Placebo Test

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	RGGI region				New England			
APEMR	0.02	0.05	0.01	0.14	0.03	0.06	0.04	0.08
Pre-int RMSPE	0.26	0.21	0.04	0.13	0.44	0.25	0.08	0.07
Estimated impact	0.12	-0.33	0.15	-0.09	0.69	-0.33	0.24	0.19
RMSPE Rank	27	26	7	40	20	27	11	25
P-value	0.65	0.63	0.15	0.98	0.48	0.65	0.25	0.60
Donor probability	0.68	0.65	0.18	1.00	0.50	0.68	0.28	0.63
	New York				Maryland-Delaware			
APEMR	0.06	0.06	0.02	0.09	0.01	0.03	0.01	0.26
Pre-int RMSPE	0.65	0.23	0.05	0.11	0.26	0.19	0.10	0.10
Estimated impact	-0.13	-0.51	0.15	-0.23	-0.17	-0.41	0.35	-0.30
RMSPE Rank	39	23	9	31	23	22	10	26
P-value	0.95	0.55	0.20	0.75	0.55	0.53	0.23	0.63
Donor probability	0.98	0.58	0.23	0.78	0.58	0.55	0.25	0.65

Notes: (a) This 'time placebo' test uses the horizon 1990-2008 and applies a placebo intervention in 2002. (b) APEMR = Absolute prediction error to mean ratio, RMSPE = Root mean squared prediction error, Estimated impact is post-intervention difference between actual and synthetic, RMSPE Rank = post- to pre-intervention RMSPE ratio. (c) Columns 1 and 5: total CO_2 emissions; Columns 2 and 6: CO_2 emissions from total electricity generation; Columns 3 and 7: CO_2 emissions from coal generation; Columns 4 and 8: CO_2 emissions from natural gas generation.

Table 5: SCM Estimates of the Impact of Cap and Trade on Per Capita CO_2 Emissions – Pre-intervention Characteristics Match

	(1)	(2)	(3)	(4)		(5)	(6)	(7)	(8)	
Panel A: Main set of predictors										
	Synthetic RGGI				Actual	Synthetic New England				Actual
Coal- to tot generation	0.07	0.11	0.15	0.40	0.24	0.19	0.16	0.11	0.71	0.16
NG- to total capacity	0.11	0.24	0.17	0.26	0.28	0.20	0.21	0.17	0.28	0.25
total net generation	16.08	16.10	16.09	16.34	15.90	16.22	16.13	16.08	16.13	15.95
Education: college	22.54	22.25	21.90	24.37	28.82	23.12	21.49	21.69	30.25	30.25
Commercial Sales	4.27	3.97	4.45	3.39	3.37	4.43	4.39	4.46	4.02	3.35
Personal income	3.33	3.40	3.32	3.52	3.62	3.39	3.35	3.31	3.52	3.63
Residential customers	39.65	38.35	41.27	38.05	38.06	42.18	41.27	40.96	41.36	41.40
	Synthetic New York				Actual	Synthetic Maryland-Delaware				Actual
Coal- to tot generation	0.01	0.10	0.12	0.43	0.17	0.23	0.35	0.43	0.47	0.59
NG- to total capacity	0.11	0.14	0.15	0.23	0.34	0.16	0.14	0.20	0.21	0.17
total net generation	15.99	16.06	16.03	16.38	15.81	16.20	16.15	16.19	16.26	16.02
Education: college	21.09	21.85	22.58	23.72	27.31	24.15	23.99	26.24	27.12	30.24
Commercial Sales	4.60	3.98	4.47	3.15	3.20	3.74	3.37	3.67	3.83	3.93
Personal income	3.27	3.35	3.32	3.39	3.62	3.43	3.42	3.45	3.53	3.61
Residential customers	40.81	38.41	40.63	35.81	35.64	38.23	38.00	37.98	38.69	37.98
Panel B: Alternative set of predictors										
	Synthetic RGGI				Actual	Synthetic New England				Actual
NG- to tot generation	0.11	0.03	0.27	0.14	0.22	0.18	0.20	0.11	0.17	0.25
Coal- to total capacity	0.07	0.07	0.08	0.31	0.16	0.14	0.10	0.07	0.17	0.10
% homeowners	69.25	60.44	65.42	59.53	58.87	67.96	67.74	70.39	65.63	63.96
Industrial Revenue	0.20	0.27	0.24	0.30	0.14	0.14	0.20	0.23	0.14	0.18
Total Sales	14.95	12.47	13.72	10.65	8.35	13.56	14.24	15.97	12.64	8.30
FDI	-6.30	-5.37	-5.38	-5.05	-5.72	-6.19	-5.81	-6.40	-5.91	-5.76
Personal income	3.34	3.50	3.37	3.45	3.62	3.40	3.36	3.30	3.47	3.63
Residential customers	41.26	36.97	38.43	36.80	38.06	43.12	40.74	40.88	42.19	41.40
Industrial customers	0.60	0.21	0.54	0.15	0.13	0.36	0.53	0.74	0.20	0.20
	Synthetic New York				Actual	Synthetic Maryland-Delaware				Actual
NG- to tot generation	0.06	0.04	0.31	0.17	0.26	0.08	0.10	0.05	0.04	0.06
Coal- to total capacity	0.01	0.06	0.07	0.11	0.11	0.17	0.27	0.30	0.40	0.40
% homeowners	71.25	61.20	61.55	56.43	52.60	66.53	66.75	66.96	63.72	66.96
Industrial Revenue	0.24	0.25	0.23	0.34	0.10	0.29	0.26	0.26	0.26	0.18
Total Sales	16.73	13.14	10.62	8.66	7.35	13.35	11.93	11.61	11.13	11.61
FDI	-6.54	-5.48	-4.39	-4.35	-5.67	-5.86	-5.69	-5.77	-5.51	-5.85
Personal income	3.27	3.50	3.45	3.50	3.62	3.40	3.41	3.41	3.45	3.61
Residential customers	40.81	38.01	36.30	32.54	35.64	38.61	38.40	37.98	37.98	37.98
Industrial customers	0.84	0.24	0.30	0.08	0.06	0.44	0.30	0.30	0.20	0.17

Notes: (a) The 'main set of predictors' corresponds to the results in Table 2, 'alternative set of predictors' corresponds to the results in Table 3. (b) Columns 1 and 5: total CO_2 emissions; Columns 2 and 6: CO_2 emissions from total electricity generation; Columns 3 and 7: CO_2 emissions from coal generation; Columns 4 and 8: CO_2 emissions from natural gas generation.

Table 6: Per Capita Personal Income Growth Rate for Actual and Synthetic Region

Region	Period	(1)	(2)	(3)	(4)	Actual Growth Rate
		Synthetic Average Growth Rate				
New York	Pre-intervention	4.1	4.0	4.1	4.2	4.1
New York	Post-intervention	2.9	2.7	2.8	2.2	3.1
RGGI states	Pre-intervention	4.1	4.0	4.1	4.1	4.3
RGGI states	Post-intervention	2.8	2.7	2.8	2.5	2.7
New England	Pre-intervention	4.1	4.0	4.1	4.3	4.5
New England	Post-intervention	2.6	2.6	2.8	3.0	2.5
MD-DE	Pre-intervention	4.1	4.1	4.2	4.3	4.2
MD-DE	Post-intervention	2.5	2.6	2.6	2.4	2.2

Note: (a) Synthetic average growth rate is the W-weighted average growth rate of the donor pool based on the main results in Table 2. (b) Column 1: total CO_2 emissions; Column 2: CO_2 emissions from total electricity generation; Column 3: CO_2 emissions from coal generation; Column 4 CO_2 emissions from natural gas generation.

Table 7: SCM Estimates of the Impact of Cap and Trade on CO_2 Emissions – The 'Leakage' Issue

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	RGGI region				New England			
APEMR	0.02	0.04	0.01	0.06	0.03	0.05	0.05	0.13
Pre-int RMSPE	0.33	0.16	0.03	0.07	0.38	0.20	0.07	0.14
Estimated impact	-1.23	-0.55	-0.67	0.16	-0.71	-0.54	-0.62	0.22
RMSPE Rank	5	10	1	22	18	13	1	23
P-value	0.11	0.25	0.00	0.58	0.47	0.33	0.00	0.61
Donor probability	0.14	0.28	0.03	0.61	0.50	0.36	0.03	0.64
	New York				Maryland-Delaware			
APEMR	0.05	0.07	0.03	0.14	0.01	0.02	0.02	0.11
Pre-int RMSPE	0.58	0.23	0.05	0.18	0.23	0.18	0.12	0.05
Estimated impact	-1.74	-0.54	-0.53	0.24	-1.30	-1.01	-1.38	0.27
RMSPE Rank	9	15	1	28	2	4	1	11
P-value	0.22	0.39	0.00	0.75	0.03	0.08	0.00	0.28
Donor probability	0.25	0.42	0.03	0.78	0.06	0.11	0.03	0.31

Notes: (a) The donor pool now has 35 states (Ohio, Pennsylvania, Virginia and West Virginia are excluded from the main donor pool in Table 2). (b) APEMR = Absolute prediction error to mean ratio, RMSPE = Root mean squared prediction error, Estimated impact is post-intervention difference between actual and synthetic, RMSPE Rank = post- to pre-intervention RMSPE ratio. (c) Columns 1 and 5: total CO_2 emissions; Columns 2 and 6: CO_2 emissions from total electricity generation; Columns 3 and 7: CO_2 emissions from coal generation; Columns 4 and 8: CO_2 emissions from natural gas generation.

Table 8: SCM Estimates of the Impact of Cap and Trade on CO_2 Emissions – Leakage from Ohio, Pennsylvania, Virginia and West Virginia

	Ohio			Pennsylvania		
	Per Capita Electricity Generation			Per Capita Electricity Generation		
	total	from coal	from natural gas	total	from coal	From natural gas
APEMR	0.02	0.02	0.14	0.01	0.02	0.15
Pre-int RMSPE	0.41	0.36	0.02	0.24	0.25	0.10
Estimated impact	-1.94	-1.80	1.05	0.83	-1.11	2.05
RMSPE Rank	5	7	1	6	7	5
P-value	0.11	0.17	0.00	0.14	0.17	0.11
Donor probability	0.14	0.19	0.03	0.17	0.19	0.14
	Virginia			West Virginia		
APEMR	0.04	0.04	0.18	0.04	0.06	0.30
Pre-int RMSPE	0.52	0.26	0.17	2.50	3.30	0.04
Estimated impact	-0.57	-1.08	1.66	-8.60	-1.05	-0.14
RMSPE Rank	14	10	7	9	32	17
P-value	0.36	0.25	0.17	0.22	0.86	0.44
Donor probability	0.39	0.28	0.19	0.25	0.89	0.47

Notes: (a) The donor pool now has 35 states (Ohio, Pennsylvania, Virginia and West Virginia are excluded from the main donor pool in Table 2). (b) APEMR = Absolute prediction error to mean ratio, RMSPE = Root mean squared prediction error, Estimated impact is post-intervention difference between actual and synthetic, RMSPE Rank = post- to pre-intervention RMSPE ratio.