The Impact of Cap and Trade on Consumer Energy Prices: An Empirical Study of the Regional Greenhouse Gas Initiative

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Abstract

Greenhouse gas emissions continue to cause climate change, and in the US, 25% of greenhouse gas emissions come from the energy sector. In order to combat this, regulatory authorities implement a variety of policies. One such policy is the Regional Greenhouse Gas Initiative (RGGI), which uses a cap and trade system to reduce emissions and was implemented in 2009. However, for the policy to be truly successful, the burden should not be placed on consumers. This study tests two hypotheses: (1) consumer energy prices have been reduced as a result of the policy, and (2) that there is significant evidence of leakage in the region, which challenged the validity of the results of the first model. In this study, I use a difference in differences model in order to determine the average treatment effect on the treatment group. The results suggest that prices have decreased in the RGGI region by between 6% and 15%. However, the results also suggest that imports of energy from unregulated states in the region increased by about 15%, which points to evidence that firms were able to circumvent the cap and trade policy. In other words the price benefits are most likely a result of firms evading the policy and not from the benefits associated with reducing emissions, such as an increase in renewable energy. The results of this study highlight the issues surrounding regulation of power plants rather than firms and how incomplete regulation can result in inefficient outcomes. Moreover, it reveals an important gap in the study of Environmental Economics. In order for future cap and trade programs to be successful, regulators will need to prevent leakage.

Introduction

Rising greenhouse gas emissions from the use of fossil fuels have resulted in climate change, wherein global temperatures are on the rise, there are more intense and frequent storms and natural disasters, increasing drought duration and severity, rising ocean levels, and a loss of biodiversity (NOAA, 2021). In the US, 25% of greenhouse gas emissions come from the power sector (EPA, 2023). The power sector refers to the actual generation of electricity using fossil fuels, renewable sources, and nuclear (EPA, 2023). Because renewable and clean energy sources produce no greenhouse gas emission, the integration of these sources into the US power grid is thus a critical step towards reducing greenhouse gas emissions. In absence of regulation, firms have no external incentive to reduce their emissions and invest in renewable energy (Keohan & Olmstead, 2007). There are many ways for the government to push for renewable integration, including subsidies and tax breaks for firms that produce renewable energy, as well as increased taxes and regulations for heavily emitting firms (Vig & Kraft, 2019).

A cap and trade system is one example of a policy with these goals in mind. It offers regulators an avenue with which to incentivize investment in renewable energy as well as reducing the greenhouse gas emissions in the energy sector (Keohan & Olmstead, 2007). Under a cap and trade system, regulators create a limit for emissions in a given region then issue and auction a certain number of permits to emit greenhouse gas emissions to utilities and firms(Keohan & Olmstead, 2007). Firms then buy and sell permits as needed, so that heavily emitting firms purchase a lot of these permits and low emitting firms require less (Keohan & Olmstead, 2007).

The fundamental economic theory behind cap and trade are social costs (Keohan & Olmstead, 2007). The notion of social costs was first proposed by Arthur Pigou in 1921 and later refined by Ronald Coase in 1960. Ronald Coase argues that under conditions of clearly defined property rights and negligible transaction costs, the allocation of resources will be efficient regardless of the initial assignment of those rights (Coase, 1960). This theory was then adapted to the study of Environmental Economics, but instead of the allocation of resources it is the allocation of emissions (Keohan & Olmstead, 2007). Firms emit greenhouse gasses, which are costly to society, but firms do not fully account for such damages in absence of regulation (Kolstad, 2011). In other words, there is no increased cost for using heavily emitting sources such as coal in absence of regulation (Kolstad, 2011). Additionally, there is neither a penalty for increasing emissions nor a tangible incentive to reduce them (Kolstad, 2011). Once a cap and trade system is in place, firms face an increase in their production costs which is directly related to their emission level (Kolstad, 2011). In other words, for every additional unit of emissions they produce, their total costs will increase (Kolstad, 2011). Firms are therefore incentivized to reduce their emissions as much as possible in order to lower their costs (Kolstad, 2011). In addition, cap and trade systems provide an additional incentive for firms to further reduce their emissions because they are able to generate revenue by selling their unused or unneeded permits to other firms or back to the regulators (Chen et al., 2020).

One such cap and trade system in the US that saw resounding success was the sulfur dioxide (SO2) allowance trading program set up under the 1990 Clean Air Act Amendments (Stavins, 2012). Sulfur dioxide rates were high because firms were using high-sulfur coal from predominantly the midwest (Stavins, 2012). Sulfur dioxide is the leading cause of acid rain (Stavins, 2012). Acid rain can be extremely harmful to forests, groundwater, lakes, rivers, buildings, and has been shown to cause respiratory harm (US EPA, 2016). The cap and trade system was intended to reduce total annual SO2 emissions in the US by ten million tons relative to 1980 (Stavins, 2012). Instead that figure was far surpassed, and by 2007 annual SO2 emissions saw a 43% reduction compared to 1990 levels (Stavins, 2012). Furthermore, the system contributed to significant cost reductions to firms compared to the original forecasted cost of this regulation (Stavins, 2012, & Ellerman, 2003). Additionally, consumers experienced little to no price increases (Stavins, 2012, & Ellerman, 2003)

In the US, the Regional Greenhouse Gas Initiative (RGGI) cap and trade system was put into effect in 2009 in Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey (New Jersey left the program in 2011), New York, Rhode Island, Vermont, and parts of Virginia. This cap and trade regulates carbon dioxide emissions Permits are auctioned and allocated to polluting firms within each state. The policy regulates power plants with a nameplate capacity of more than 25-megawatt hours. As a result of the policy, greenhouse gas emissions have seen a sharp decline in the region on paper (Murray et al., 2014). However, for the policy to truly be successful, the burden of the regulation should not be placed on the consumers.

There are a few key differences between the RGGI system and the 1990 sulfur dioxide system. Most noticeably, the difference in marginal damages between carbon emissions and sulfur dioxide. Marginal damages refer to the increase in social harm and risk associated with producing one more unit of emissions (Kolstad, 2012). Sulfur dioxide presents a more clear and present danger with acid rain than carbon dioxide does with climate change (US EPA, 2012 & NOAA, 2021). As a result, there was more political pressure on both regulators and firms to reduce their sulfur dioxide emissions and the policy was able to be more stringent on firms (Stavins, 2012). Additionally, the available methods of abatement are different between the two systems. Abatement is the process of reducing emissions via a variety of options, including technological innovation, fuel switching, and installing end-of-pipe technology (Van den Bergh

& Delarue, 2015). Under the sulfur dioxide program, firms switched from high-sulfur coal to lower sulfur coal which was an extremely effective and cost efficient way to abate (Van den Bergh & Delarue, 2015). Because the RGGI program focuses on carbon emissions, switching the type of coal does work. There is no significantly lower-emitting type of coal to switch to, and this method can not be used for abatement (U.S. Department of Energy. 2023.) Additionally firms were able to integrate natural gas plants into their production, as natural gas only emits trace amounts of sulfur dioxide (Burnham et. al, 2012). Finally, the sulfur dioxide program was mandated for the contiguous United States (Stavins, 2012). On the other hand, the RGGI cap and trade program is voluntary for states, and it is isolated in the north-eastern states. That being said, the RGGI system has a number of exogenous factors that are in its favor. Most importantly, the unprecedented improvements in renewable energy.

Recently, renewable energy has become more cost effective to produce than using fossil fuels in the long run. As demonstrated in Figure 1, the global Levelized Cost of Energy (LCOE) for many renewable energy technologies has seen a drastic decrease in recent years (Lazard, 2023). The Levelized Cost of Energy is a metric designed by the Lazard Bank (Lazard, 2023). It is measured as the combination of capital costs, performance costs, and operation costs (known as lifetime costs) of a given energy source divided by the energy generation capacity and lifetime expectancy of that energy source (Lazard, 2023). Moreover, the LCOE for renewable energy technologies is approaching that of natural gas, and has become lower than some fossil fuel inputs such as coal (Lazard, 2023). For instance, around 2010 solar photovoltaic energy was relatively cost effective, but was not energy efficient (Lazard, 2023). However, due to recent technological innovations, solar photovoltaics are far more efficient and can generate a lot more energy (Lazard, 2023). On the other hand, we have reached the upper bounds in the efficiency of fossil fuel sources (Burnham et. al, 2012). Moreover, recent geopolitical events such as the war in Ukraine as well as the Israeli-Palestinian conflict have highlighted the increasing costs in fossil fuels. This is most apparent in the price for natural gas and oil. Because of the lower Levelized Cost of Energy, renewable energy has seen a recent increase in many state's generation profiles (Bates, 2023). Furthermore, this provides an additional incentive for utilities to develop renewable energy production plants (Bates, 2023). In other words, firms and utilities are seeing more "bang for their buck", so to speak.

In economic theory, the price of a good is typically determined by a consumer's willingness to pay and the supply of a product in a market (Keohan & Olmstead, 2007). However, for utilities, the price consumers pay is more dependent on the marginal costs incurred by the utilities to produce that energy (Joskow et al., 2007). This is because utilities operate as regulated natural monopolies (Joskow et al., 2007). In economics, a monopoly is a firm that doesn't face significant competition in its market (Joskow et al., 2007). This can cause significant price gouging for customers, as they have no other options to buy a good (in this case, electricity)(Joskow et al., 2007). Natural monopolies arise when there is a significantly high barrier to entry in a market, but the government believes the services provided by the monopoly are necessary (Joskow et al., 2007). In exchange for letting these natural monopolies exist and operate without competition, the government keeps a close eye on the price they set (Joskow et al., 2007 & Kolstad, 2011). They regulate price in response to a firm's marginal cost (Kolstad, 2011). Marginal cost is a measure of how much it costs a firm to produce one more unit of a good or service (Kolstad, 2011). Under market-based regulation like cap and trade, firms are forced to internalize emissions generated by the production process, which effectively raises their marginal cost (Kolstad, 2011 & Van den Bergh & Delarue, 2015). While this sounds like a bad thing, it introduces an element of competition in the market which in turn should theoretically lower consumer prices. Firms compete in reducing their emissions as much as possible (Chen et al., 2020). Moreover, cap and trade policies provide an additional incentive for firms to reduce their emissions via abatement in order to generate a profit when selling off unused and unneeded permits (Chen et al., 2020).

You-hau Chen et al. (2020) demonstrate that firms have an increased incentive to abate under a cap and trade system (Chen, et al., 2020), while in another study, authors Kenneth Van den Bergh and Erik Delarue find that a firm's marginal abatement cost and generational marginal cost decrease overtime when firms abate by fuel switching (Van den Berg & Delarue, 2015). Marginal abatement costs describe the cost of a firm to reduce their emissions by one more unit. When firms switch from a high-carbon emitting fuel, such as coal, to a low-emitting fuel or renewable energy, they emit less greenhouse gasses (Chen, et al. 2020). Moreover, the costs they face from the regulation are lower (Chen, et al. 2020). Finally, as previously stated, the levelized cost of renewable energies has fallen significantly in recent years. This further increases the benefits firms realize when using fuel switching as a means of abatement (Lazard 2023). Stemming from this relation, I have developed a theory that consumer prices should have decreased in the long run under the cap and trade policy compared to the absence of such policy.

However, a fundamental issue with the RGGI cap and trade program is that it is an example of incomplete regulation. Incomplete regulation occurs when rules and regulations only apply to a subset of the sources contributing to a problem (Fowlie, 2009). The RGGI cap and trade policy applies to energy generation within the regulated states but does not apply to energy that is generated outside of the state and then transmitted into the regulated states (RGGI, 2024). Polluting firms can mitigate the effect of regulation via leakage, where they decrease production in the regulated areas, increase production in the deregulated areas, and then send energy to the regulated region. This phenomenon has been demonstrated in theory in works by Fowlie and Elrod et al. 2020. Additionally, previous empirical studies on the RGGI region have found evidence of leakage (Murray et al. 2014 & Chan et al., 2017). Moreover, incomplete market-based regulation for emissions can, in theory, actually increase aggregate emissions (Elrod, St-Pierre, 2020). For instance, a utility may choose to increase production in an antiquated coal plant in the deregulated region in order to meet the energy demand in the regulation region. In these works, they find that leakage could have accounted for all of the emissions reductions in the RGGI region coming from Pennsylvania, Ohio, and the PJM transmission network as a whole (Murray et al. 2014 & Chan et al., 2017).

Given the decreasing Levelized Cost of Energy for renewables and the increased incentive for firms to invest in these renewable sources, I test the theory that consumer energy prices in the RGGI region have fallen as a result of the cap and trade system. This study is broken down into two hypotheses; the first being that prices have fallen and the second is that there is significant evidence of leakage in the region, which would undermine the results of the first model.

Hypothesis 1: Consumer energy prices have fallen in the RGGI region.

In order to test this hypothesis, I will be using a difference in differences model to quantify the change in state-level energy production across all sectors as a result of the RGGI cap and trade policy. In economics, difference in differences models are used to estimate causal relationships when the control and treatment group are not part of a randomized control trial (Cunningham, 2021). I will be using a state-fixed effect in order to control differential energy regulation across states. In econometrics, we use fixed effects when we believe there are time-invariant factors that we cannot currently include in our model (Cunningham, 2021). I also introduce time-series control variables for population and unemployment. This captures the change in energy production that could be a result of time-varying effects across states (Keohan et al., 2007).

Data & Operalization

The treatment group for this study is the RGGI region. I have broken this up into four sectors of power consumption; residential, commercial, industrial, and the total energy sector in aggregate.The residential sector is electricity that is used by homes. The commercial sector is electricity that is used by businesses in places such as office buildings. The industrial sector is electricity used by factories and manufacturing plants. The total energy sector is the average energy price across the aforementioned sectors. In order to test this hypothesis, I am using the South Eastern Reliability Corporation (SERC) subgrid region as a control group. The SERC is a deregulated region, which means it does not have any sort of regional greenhouse gas regulation. That being said, there are a wide variety of state and local regulations in this region that are different from those in the RGGI region on a state by state basis. For instance, some states have strict renewable portfolio standards while others do not (Upton & Snyder, 2017). Renewable portfolio standards are state and local regulators that dictate how much power produced from a firm must come from renewables (Upton & Snyder, 2017). In order to control for this differential state and local regulation, I implement a state-fixed effect which is discussed in further detail below. While the energy prices in this region are lower than the RGGI, one of the strengths of the difference in differences model is that it is able to compare these two different groups (Cunningham, 2021).

Data for this section of the study covers both regions1990 and 2022. Data on historical electricity prices comes from the U.S. Energy Information Administration (EIA)'s API accessible database. Data on historical energy consumption and production comes from the EIA as well. Unemployment and population data come from the U.S. Census Bureau. In order to measure the absolute change over time for price, production, and consumption, I have taken the logarithm of these figures. Additionally, this measure effectively reduces any skewness present in the raw data (Cunningham, 2021). The resulting coefficients do not need to be exponentiated and are interpreted as percent change (Elrod et al., 2022). I have also introduced a state fixed effect in each of the models. In regression analysis, fixed effects are a method used to control for unobserved heterogeneity that is constant across individuals or entities (Cunningham, 2021). Population and unemployment are two vital variables to control for, because they have a direct impact on the demand for energy (Munasinghe & Meier, 1993). Population directly impacts the demand for residential energy, and indirectly affects commercial and industrial demand. This relationship exists because as the population increases or decreases, the demand for energy increases and decreases in a similar fashion (Munasinghe & Meier, 1993). In other words, more people will need to use more energy. Likewise, unemployment has a direct effect on commercial and industrial demand and an inverse effect on residential demand (Munasinghe & Meier, 1993). If unemployment is low, business in a region increases their demand, and residential demand may lower (Munasinghe & Meier, 1993). The inverse is also true, where a high unemployment rate may result in a higher demand in residential sectors (Munasinghe & Meier, 1993).
State-fixed effects run regression for each state in the study. In the interest of minimizing visual

pollution, I do not include the state-fixed effects in my results tables. However, the full results tables will be available in the appendix.

Methods: Price Changes

Difference in differences is one of the most widely applied methods in economics for estimating the causal effects of programs or policies when the program was not implemented as a randomized control trial (Cunningham, 2021). I will first demonstrate the parametrization of the formal model (Cunningham, 2021). The parameterization is the same for all models in this study. The formal difference in differences parameterization is as follows:

$$\beta_0 = E(Y_C^{pre})$$

$$\delta_C = E(Y_C^{post}) - E(Y_C^{pre})$$

$$\delta_{C,T} = E(Y_T^{pre}) - E(Y)$$

$$\widehat{\delta}_{ATT} = [E(Y_T^{post}) - E(Y_T^{pre})] - [E(Y_C^{post}) - E(Y_C^{pre})]$$

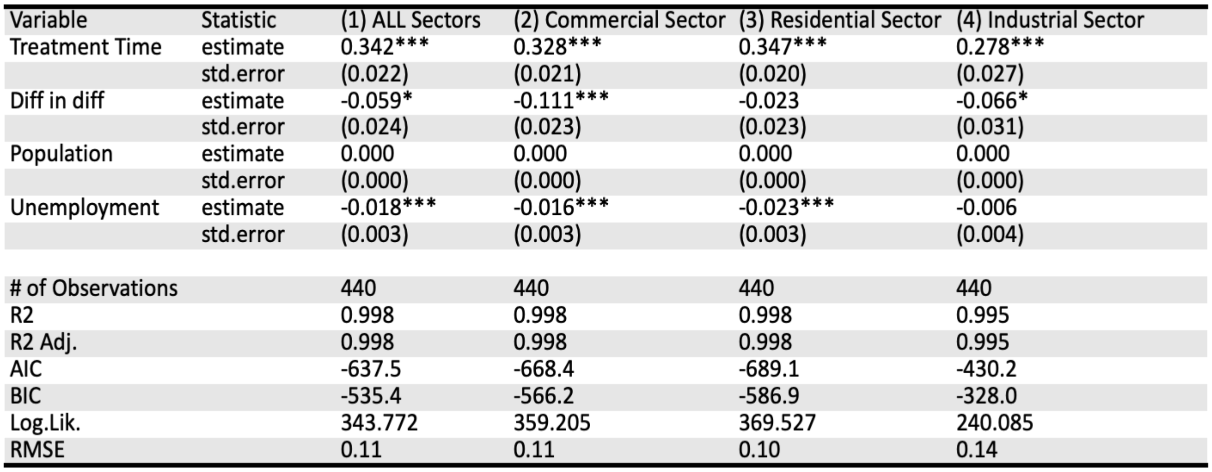
Where time before or after the policy was enacted is denoted as a dummy variable (pre = 0 , post = 1). *T* is a dummy variable that denotes the treatment group (the RGGI region), and C denotes the control group (the other 38 states). Estimates for the dependent variable *Y* use ordinary least squares to create a linear regression model. We are left with three differences: the difference between the expected dependent variable Y for the control group before and after the treatment (δ_C), the difference between the expected dependent variable Y for the treatment group and the control group before the policy was enacted, and the difference of those differences (hence the name) which results in $\widehat{\delta}_{ATT}$. $\widehat{\delta}_{ATT}$ is a measure of how much the treatment affected electricity generation, also known as the average treatment effect on the treatment group.

The formal difference in differences model I will use for this section is as follows:

$$P_{i,t} = \beta \Delta T_{i,t-1} + \widehat{\delta}_{ATT} + \beta_{U,i,t} + \beta_{P,i,t} + \beta_{state-1} + \varepsilon_{i,t}$$

Where $P_{i,t}$ is the dependent variable of electricity price in state *i* in time *t*, $\beta \Delta T_{i,t-1}$ is a measure of the control group price estimation, $\widehat{\delta}_{ATT}$ is the estimated change in electricity price as a result of the policy, $\beta_{U,i,t}$ is the control for unemployment, $\beta_{P,i,t}$ is the control for population, $\beta_{state-1}$ is the state-fixed effect, and $\varepsilon_{i,t}$ is the residual term. Table 1 provides summary statistics for this model for each sector.

Results: Price Changes



Variable	Statistic	(1) ALL Sectors	(2) Commercial Sector	(3) Residential Sector	(4) Industrial Sector
Treatment Time	estimate	0.342***	0.328***	0.347***	0.278***
	std.error	(0.022)	(0.021)	(0.020)	(0.027)
Diff in diff	estimate	-0.059*	-0.111***	-0.023	-0.066*
	std.error	(0.024)	(0.023)	(0.023)	(0.031)
Population	estimate	0.000	0.000	0.000	0.000
	std.error	(0.000)	(0.000)	(0.000)	(0.000)
Unemployment	estimate	-0.018***	-0.016***	-0.023***	-0.006
	std.error	(0.003)	(0.003)	(0.003)	(0.004)
# of Observations		440	440	440	440
R2		0.998	0.998	0.998	0.995
R2 Adj.		0.998	0.998	0.998	0.995
AIC		-637.5	-668.4	-689.1	-430.2
BIC		-535.4	-566.2	-586.9	-328.0
Log.Lik.		343.772	359.205	369.527	240.085
RMSE		0.11	0.11	0.10	0.14

Table 1

This table provides summary statistics for the price model. I've left out the results of the state fixed effects in this table in order to save space. The coefficient of interest is **Diff in diff** which is the average treatment effect on the treatment group.The full results table is located in the Full Table section.

Using a 90% confidence interval, the results suggest that the effects of the policy intervention were statistically significant for the aggregate electricity market (all sectors, Figure 2), the industrial sector (Figure 5), and the commercial sector (Figure 4). I am using a 90% confidence interval as this is a one sided test. However, we find no evidence that the effect of the policy had a significant impact on prices in the residential sector (Figure 3). The average treatment effect on the treatment group being negative demonstrates that consumer electricity prices did indeed decrease compared to what they would have been in the absence of the policy. This is represented as the Diff in diff variable in the table. The results suggest aggregate electricity prices decreased by about 6.7%, in the industrial sector by 8.8%, and about 15% in the commercial sector relative to what we would have expected in the absence of the cap and trade policy. Figures 2 -5 are located in the appendix, as well as the residual and QQ plots for each regression. As mentioned prior, we will now move on to the model to test for evidence of leakage.

Hypothesis 2: There is significant evidence that leakage has occurred in the RGGI region.

For this model, the hypothesis tested is that in-state energy production relative to consumption in the RGGI region has decreased as a result of the cap and trade policy. The implication of this model is that the price reductions seen previously may not be due to an increase in renewable energy, but rather is a result of the incomplete nature of the regulation.

Methods: Leakage

In this model, I am taking the total energy production in each state for each year and dividing it by the energy consumption. This represents the ratio of instate produced energy and imported energy from other states. States with a ratio close to 1 produce about the same energy as they consume. States with a low ratio import more energy from other states than they produce. States with a high ratio export more energy to other states than they produce. This effectively controls for each state's demand. If both consumption and production of energy changes in a similar manner, then the ratio will remain unchanged. In addition, I’ve added control variables for population and unemployment. Data for this model come from the same sources as before. Additionally, I introduce state-fixed effects once again.

Furthermore, I have broken down this model into renewable energy and fossil fuel energy in order to demonstrate that the results from the leakage model are coming from a deregulated area around the RGGI region. I do this in order to demonstrate that changes in the total ratios are a result of leakage and not a shift in production portfolios. Figure 6 provides further intuition into this relationship using purely hypothetical data. For the renewable model, the dependent variable is the ratio of renewable energy production and total energy consumption, holding the previously mentioned control variables constant as well. Likewise, the fossil fuel model examines the ratio of energy from fossil fuels and total energy consumption. In both cases, the hypothesis is that the cap and trade policy had a negative impact on this ratio.

The formal difference in difference models used for the tests on leakage is as follows:

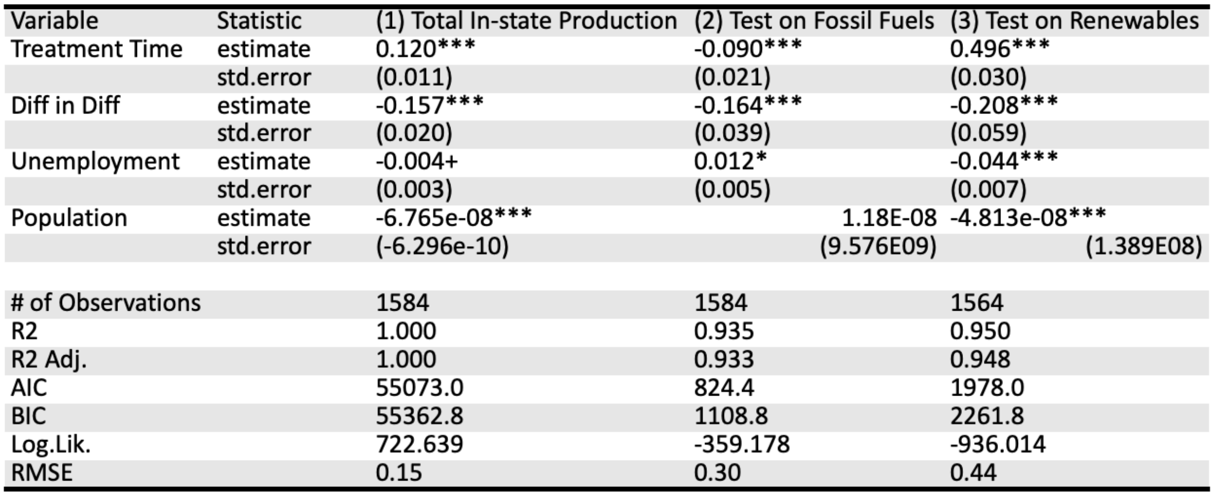
$$G_{i,t} = \beta\Delta T_{i,t-1} + \widehat{\delta}_{ATT} + \beta_{state-1} + \beta_{U,i,t} + \beta_{P,i,t} + \varepsilon_{i,t}$$

$$F_{i,t} = \beta\Delta T_{i,t-1} + \widehat{\delta}_{ATT} + \beta_{state-1} + \beta_{U,i,t} + \beta_{P,i,t} + \varepsilon_{i,t}$$

$$R_{i,t} = \beta\Delta T_{i,t-1} + \widehat{\delta}_{ATT} + \beta_{state-1} + \beta_{U,i,t} + \beta_{P,i,t} + \varepsilon_{i,t}$$

Where $G_{i,t}$ is the dependent variable for the total electricity generation ratio for state *i* in time *t*, $F_{i,t}$ is the dependent variable for the fossil fuel ratio, $R_{i,t}$ is the dependent variable for the renewable ratio, $\beta\Delta T_{i,t-1}$ is the measure of the control group’s generation, $\widehat{\delta}_{ATT}$ is the estimated change in electricity generation as a result of the policy, $\beta_{state-1}$ is a state fixed effect control variable, $\beta_{U,i,t}$ is a control variable for unemployment, $\beta_{P,i,t}$ is a control variable for population, and $\varepsilon_{i,t}$ is the residual term. Table 2 provides summary statistics for this difference in differences model.

Results: Leakage



Variable	Statistic	(1) Total In-state Production	(2) Test on Fossil Fuels	(3) Test on Renewables
Treatment Time	estimate	0.120***	-0.090***	0.496***
	std.error	(0.011)	(0.021)	(0.030)
Diff in Diff	estimate	-0.157***	-0.164***	-0.208***
	std.error	(0.020)	(0.039)	(0.059)
Unemployment	estimate	-0.004+	0.012*	-0.044***
	std.error	(0.003)	(0.005)	(0.007)
Population	estimate	-6.765e-08***	1.18E-08	-4.813e-08***
	std.error	(-6.296e-10)	(9.576E09)	(1.389E08)
# of Observations		1584	1584	1564
R2		1.000	0.935	0.950
R2 Adj.		1.000	0.933	0.948
AIC		55073.0	824.4	1978.0
BIC		55362.8	1108.8	2261.8
Log.Lik.		722.639	-359.178	-936.014
RMSE		0.15	0.30	0.44

Table 2

This table provides summary statistics for the leakage models. The coefficient of interest is **Diff in diff** which is the average treatment effect on the treatment group. I've left out the results of the state fixed effects in this table in order to save space. The full results table is located in the Full Table section.

Using a 90% confidence interval, the results suggest that the effects of the policy intervention resulted in a decrease in electricity production of 15% (Figure 7) in the RGGI region. In other words, the regulated region had a 15% increase in the amount of electricity imported from outside of the regulated region. The results from the fossil fuel model and renewable model also suggest that this is not due to a shift in the generation portfolio for the region, but rather points to clear evidence of leakage. Figure 7 is located in the appendix, as well as the residual and QQ plots for each regression.

Discussion

The results from this study suggest that consumer energy prices are between 6 and 15% lower than what they would have been in the absence of the cap and trade policy. The results also suggest that the RGGI region increased its energy imports from neighboring states by 15% which points to clear evidence of leakage. Not only has leakage heavily undermined the emission reductions from the cap and trade program (Murray et al., 2014 & Chan et al., 2019), but it could also have played a critical role in the modeled reductions in energy prices.

The effects of leakage are not the same for every state in the RGGI region. For instance, firms in Maine would not have been able to participate in leakage as much as firms in New York (Murray et al., 2014 & Chan et al., 2019). Maine is on the northernmost part of the RGGI region, and therefore firms do not have any neighboring unregulated states to leak to. New York, on the other hand, is in close proximity to unregulated states. Moreover, there are more than 300 unregulated power plants in a 40,000 square mile area of the New York and Pennsylvania border (Egrid, 2022). Because of this, firms closer to the southern border of the RGGI region have a significant advantage over firms further away. This relationship is further represented when likening this kind of incomplete regulation to offshoring. Take, for example, the reliance of imported goods from China in the United States. Manufacturers in China often have significantly lower cost structures than manufacturers in the United States because of a number of factors including lower labor costs, comparatively less labor regulations, and lower production costs (Kjeldsen-Kragh, 2002). If the same product is produced in both China and the United States, the firm(s) in China have a significant comparative advantage (Kjeldsen-Kragh, 2002). This environment is similar to the RGGI system in both theory and practice (Fowlie, 2009).

This comparative advantage effect is further exacerbated by the cap and trade system. As mentioned prior, firms are incentivized to reduce their emissions by abatement, investment in renewable energy, and, in this case, to participate in leakage. Because some regions of the RGGI can participate in leakage, they are able to quickly reduce emissions and generate profit by selling the unused and unneeded permits to firms in areas that cannot participate in leakage

(Kjeldsen-Kragh, 2002, Fowlie, 2009, & Elrod et al., 2022). This effectively drives the competitive price for these permits higher, and firms that cannot leak suffer far worse than those who can (Fowlie, 2009 & Elrod et al., 2022). Moreover, the firms who cannot leak are faced with a decreasing demand for these permits. In other words, firms that do not or are unable to circumvent the cap and trade regulation suffer more than those who do.

The nature of the electricity grid in the region further magnifies the issues with the RGGI system. In the 1990s, reconstruction and reconfiguration of the electricity grid led to consolidated transmission networks grouped by states, known as Regional Transmission Organizations (RTOs) (Hogan, 2021 & Davis et al., 2023). In the RGGI region, there are three of these RTOs: the Pennsylvania-New Jersey-Maryland (PJM), the New York ISO (NYISO) and the New England ISO (ISO-NE). Figure 8 shows the areas of these different RTOs. Each of these regions has unique advantages and disadvantages, but the most important in the context of this study is how supply and demand for energy is organized in the PJM (Hogan, 2021). Firms and utilities that operate in this RTO do not face an increased cost for transmitting electricity across state borders (Hogan, 2021). Furthermore, transmission networks were set up in order to facilitate this transfer of electricity based on the costs associated with each producer (Hogan, 2021). In practice, when it becomes more expensive to produce energy in one state of the PJM firms are able to increase their production in a cheaper state and transmit that energy to the more expensive state (Hogan, 2021 & Davis et al., 2023).While this was intended as a measure to reduce consumer energy prices, it also unintentionally laid the groundwork for firms to circumvent incomplete regulation. Just as the results of this study suggest, prices went down because firms were able to circumvent the regulation.

That being said, this offers new insight in analyzing the effectiveness of cap and trade, and identifies important obstacles for regulators to overcome. Liking participation of leakage to that of offshoring, it may be possible to estimate how cap and trade impacted the firms' marginal costs functions. Because firms keep both their marginal production costs and marginal abatement costs confidential, we need to use empirical analysis to estimate the effect regulation has on them (Van den Berg & Delarue, 2015). Once there is a better sense of how cap and trade impacts firms, regulators are better equipped to set efficient caps and allocate the efficient amount of permits (Van den Berg & Delarue, 2015). This is an important gap in the literature surrounding energy economics, and it is something I hope to study and continue my education around.

This study further highlights the issues surrounding regulation of power plants rather than firms. When regulating the power plants, firms have the ability to participate in leakage. However by regulating the firms themselves, there is nowhere to leak to. As a result, this would preserve the desired competitive nature of cap and trade, and the only way for firms to reduce their emissions would be to invest in abatement technologies and renewable energy. While this may increase consumer energy prices, it would reduce greenhouse gas emissions which is the end goal of this kind of regulation. Another option would be to implement a nation-wide cap and trade program. Under this program, firms would not have anywhere to leak to, and would result in reduced greenhouse gas emissions.

The biggest obstacle to these solutions would be political feasibility. Just like with any kind of regulation, firms would lobby the local, state, and federal governments in opposition to regulation (Tillman & Park, 2009). Moreover, voters may express significant opposition on the grounds that their electricity bill would increase (Tillman & Park, 2009). Voters are sensitive to increases in any kind of tax, and firms could argue that this kind of regulation would, in effect, increase the price of electricity (Tillman & Park, 2009). However, if we are able to demonstrate that energy prices would fall in the long run and greenhouse gas emissions would be reduced then future cap and trade policies would be far more politically feasible

Assumptions and Limitations

Difference in differences relies upon the parallel trend assumption, as well as the standard assumptions for OLS regression (Cunningham, 2021). The parallel trend assumption implies that in the absence of a treatment, the trend for both the control and treatment group will be equal. In other words, the trends for both groups before treatment and the control group after treatment is a good indicator of what would have happened in absence of treatment. This generates a counterfactual, as there is no world in which the policy is not enacted. Therefore, we must estimate what would've happened. While there is no statistical method to test the parallel trend assumption (Cunningham, 2021), implementing a placebo test is an effective way to increase the validity of the models in this study. A placebo test involves changing the states in the treatment group to those that have no policy intervention, then seeing what impact the placebo treatment had on them (Cunningham, 2021). If the results of the placebo study are not significant, it effectively increases the validity of the actual models (Cunningham, 2021). While that is unfortunately out of the scope of this study, I hope to implement this placebo test in future research.

Another important limitation of this study is the fact that I am looking at annual data on energy price, production, and consumption as opposed to hourly data. Energy price, production, and consumption is heavily impacted by daily energy surges (Islam, 2020). For instance, energy demand peaks around 5:00 in the afternoon when everyone is getting off work, turning on the

TV, turning up the air conditioner, cooking dinner, and everything in between (Islam, 2020). As a result, utilities are forced to ramp up energy production, and have historically used coal to meet the peak demand (Islam, 2020). Some firms are better equipped to meet this demand and it is one of the strengths of the PJM network (Hogan, 2021). By using hourly data, I would be able to denote the difference between utilities participating in leakage and meeting that peak demand. Moreover, I would be able to more accurately measure the changes in energy price. I was unable to do this due to the vast size of data associated with hourly data over 30 years (about 13 million observations).

Conclusion

The RGGI cap and trade system was put in place in 2009 with the intent to lower carbon dioxide emissions from the energy sector. With the Levelized Cost of Energy seeing drastic reductions in many renewable sources over the past two decades, I test the theory that consumer energy prices have lowered in the region as a result of the policy. While the preliminary test on consumer prices showed promising results, the tests on leakage show that an unknown amount of price reductions are the result of incomplete regulation and not an increase in renewable energy. Moreover, there is a gap in the literature with a way to link the impact that leakage has on consumer energy prices as a result of market-based policy.

The uncertainty of the results of this study highlights how incomplete market-based approaches can be inefficient. Leakage is not an intended part of cap and trade programs, but it seems to be its Achilles heel. For future cap and trade programs to be successful, regulators need to find a way to eliminate the possibility of leakage by introducing stiff penalties, disincentivizing it, or expanding the scope of the regulation to a degree such that firms have nowhere to leak to. Another possible solution would be to regulate the firms directly, which would be able to control leakage within firms and could be applied to a smaller number of firms or states.

That being said, cap and trade systems work very well in theory when eliminating leakage. The sulfur dioxide cap and trade program shows just how promising this kind of regulation is in both reducing harmful emissions and minimizing the impact it has on consumers. This study highlights the importance of limiting incomplete regulation. Moreover, it highlights the importance of in depth and thorough analysis of policy. As mentioned prior, greenhouse gas emissions have gone down in the region. Additionally, my model shows that prices have gone down as well. If taken at face value without any consideration of intricate factors such as incomplete regulation, we run the risk of implementing more inefficient and bad policies. Further research and study is needed in order to model the impact leakage has on consumer prices, as well as a way to model what these kinds of regulations should look like in absence of leakage.

Acknowledgements

I would like to express my gratitude to Dr. Eric Ezell and Dr. Keri Watson, department heads of Environmental Studies at Sewanee. They both had a tremendous impact on every stage of my study, and constantly offered helpful feedback on my work. Moreover, they helped me translate my sometimes excessive economic jargon into terms that can be understood by a general audience. I would also like to express my gratitude to Dr. Aaron Elrod, Department of Economics, and Dr. Patrick Gauding, Department of Politics. They both helped me develop sound theory, understand causal relationships, and interpret the statics in a way that I could not have done otherwise. Each one of my aforementioned professors had a unique, supportive, and unequivocal impact on the way I approached this study as well as the way I will approach academics in the future. Thank you all!

Appendix

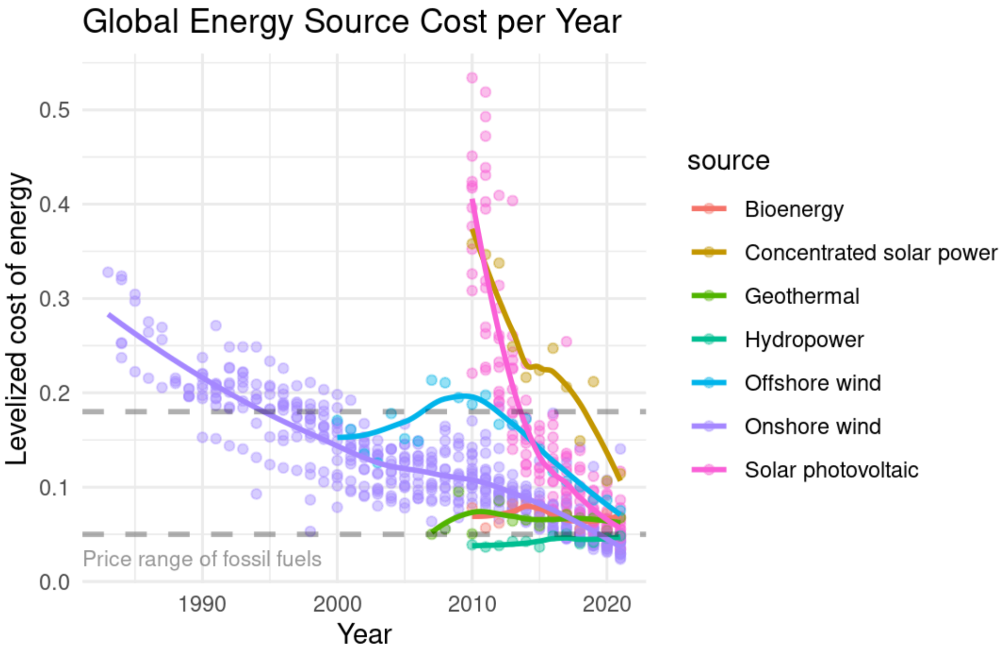


Figure 1: This graph shows the Levelized Cost of Energy for 7 different renewable energy sources. It demonstrates that recently, renewable energy has become more cost effective in some cases compared to fossil fuels. Data comes from OurWorld in Data.

Figure 2: This graph shows the difference in differences model for the RGGI region as a whole. The average treatment effect for this section was a price reduction of 6%

Figure 3: This graph shows the price change difference in differences model for the residential sector in the RGGI region. Unfortunately, the results from this model were not statistically significant.

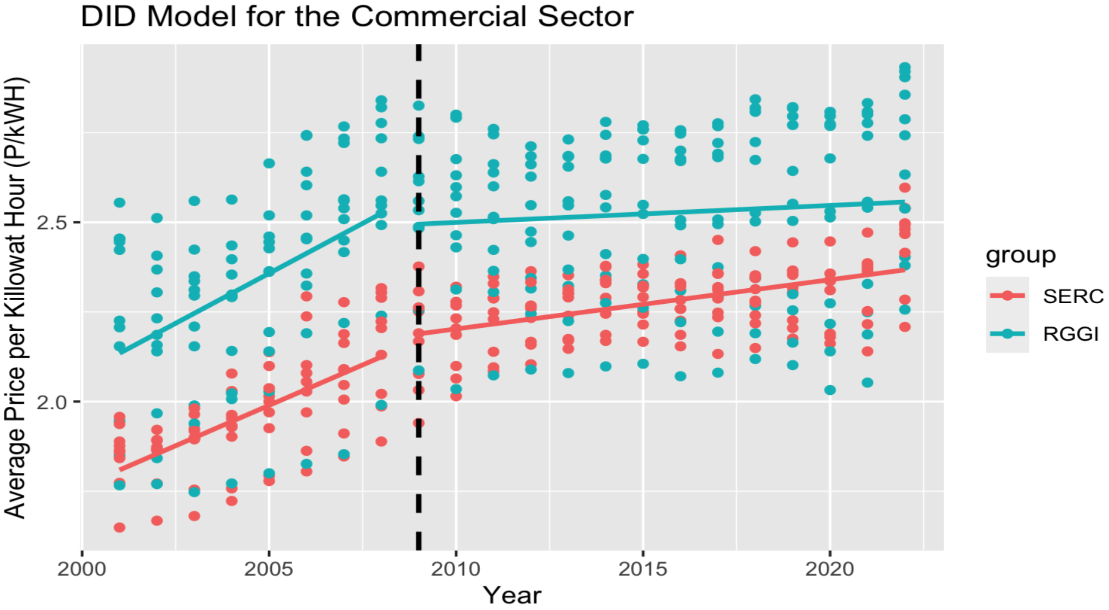


Figure 4: This graph shows the price change difference in differences model for the commercial sector of the RGGI region. The results from this model indicate that prices were reduced by 15% in the region.

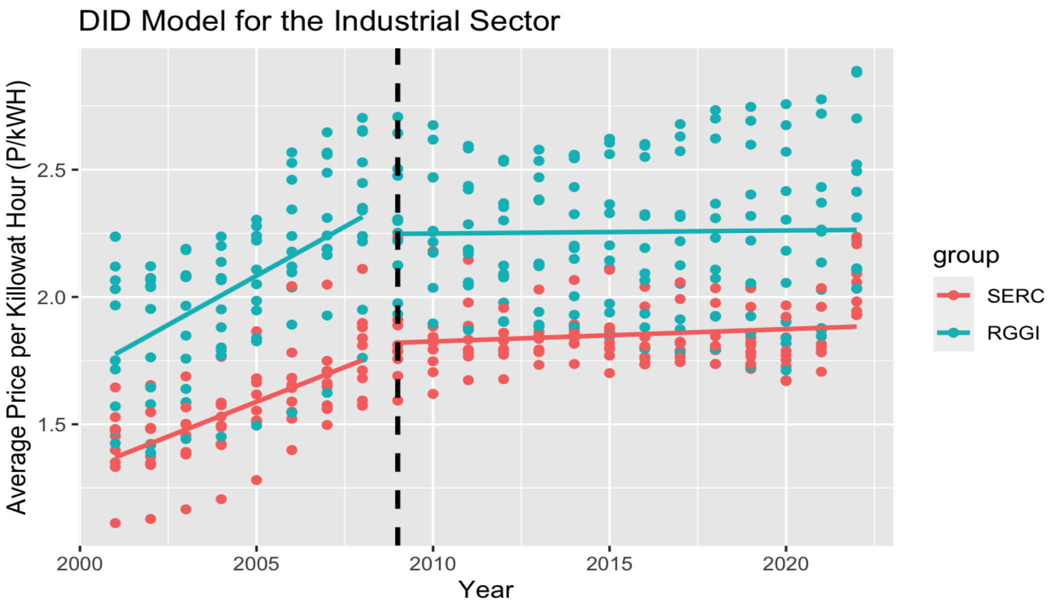


Figure 5: This graph shows the price change difference in differences model for the industrial sector of the RGGI region. The results from this model indicate that prices were reduced by 8.7% in the region

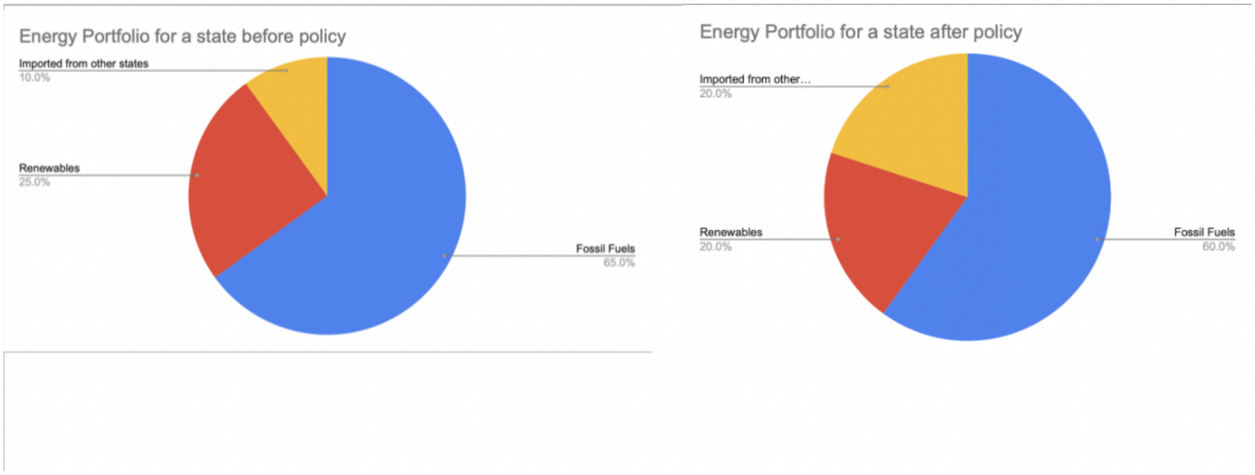


Figure 6: These two charts show the relationship between leakage and instate production portfolios using purely hypothetical data. On the left is the mix before policy intervention, and on the right is the mix after policy intervention. It shows that the portion of imported energy increases, and instate production decreases.

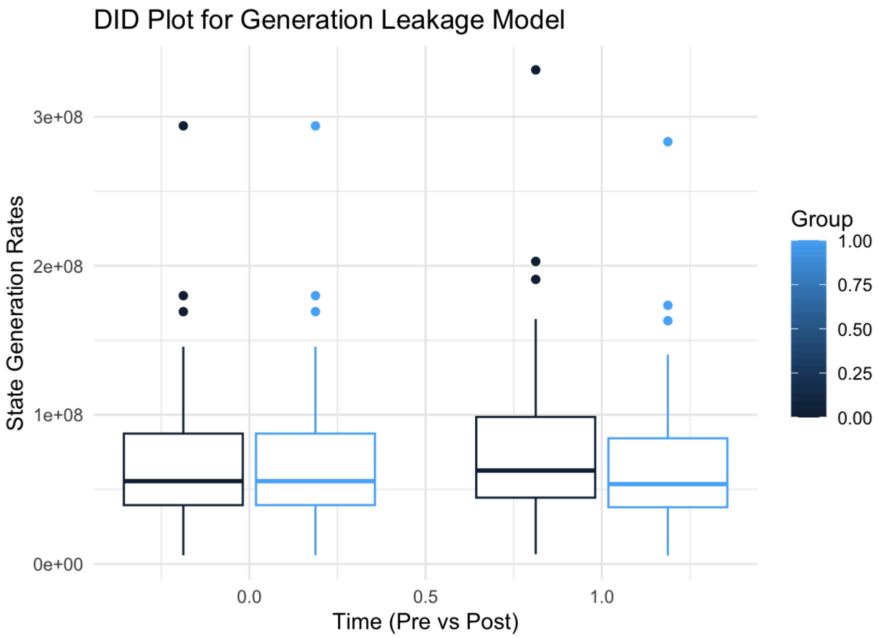


Figure 7: This graph shows the changes in instate electricity production before and after the implementation of the cap and trade policy. The results suggest that the instate, regulated energy production in the state decreased by 15%. This, while holding demand constant, provides evidence of leakage.

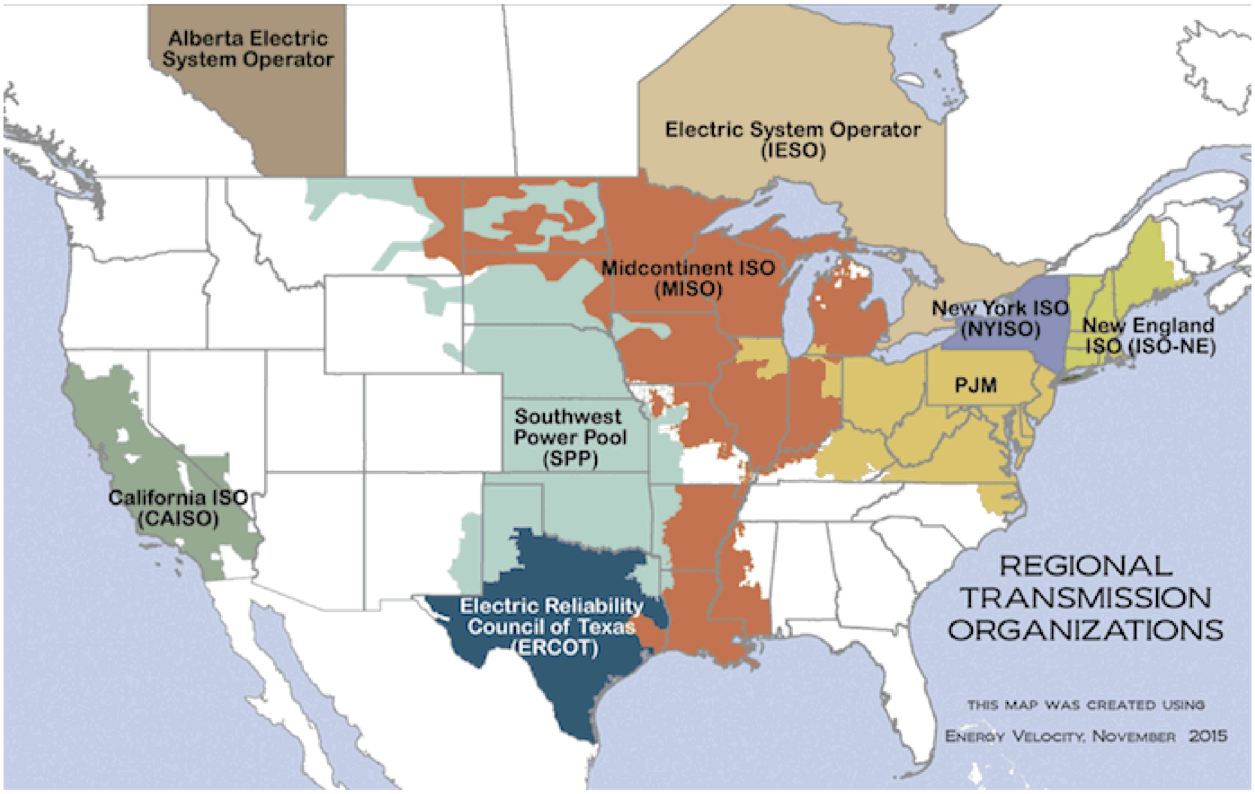


Figure 8: This is a map of the Regional Transmission Organizations in the United States. It is included to give the reader more context into the current state of the US electricity grid. It was created by Energy Freedom Colorado, and the full citation is provided in the following section.

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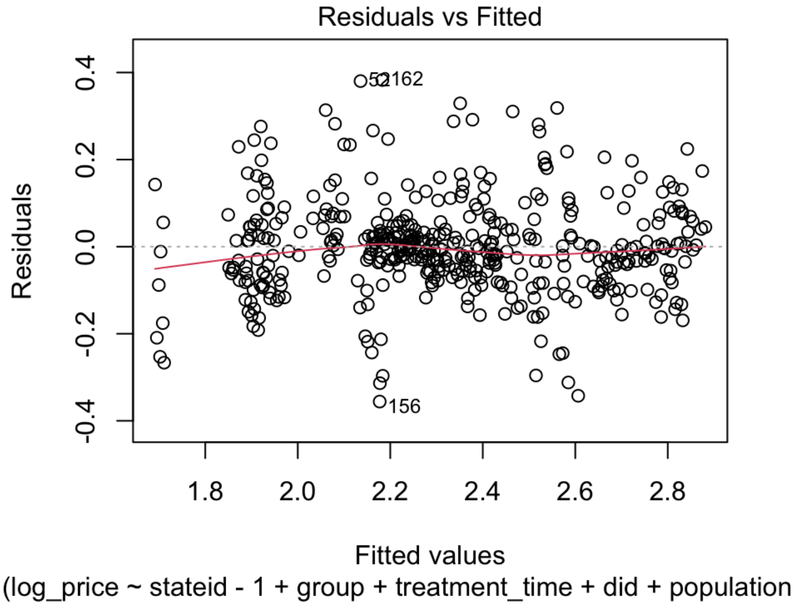
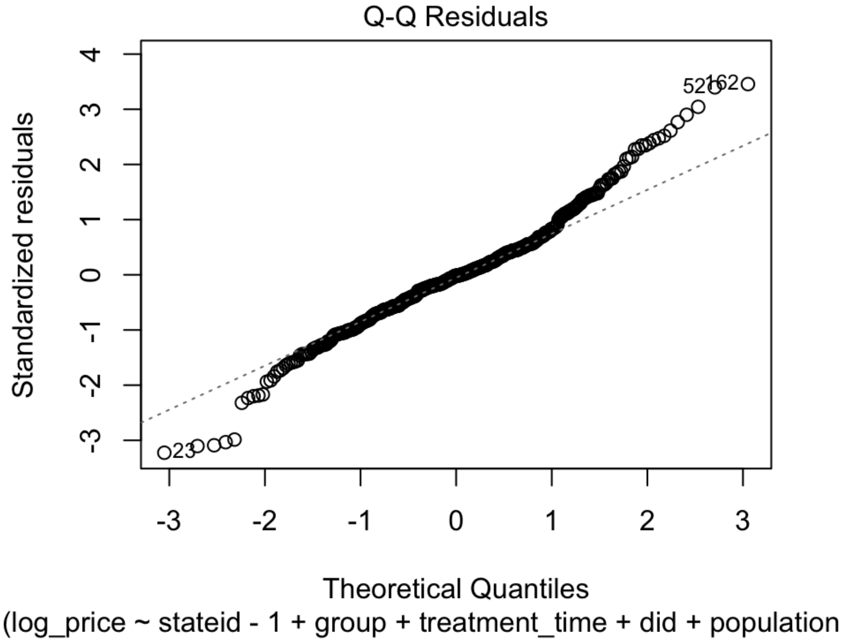
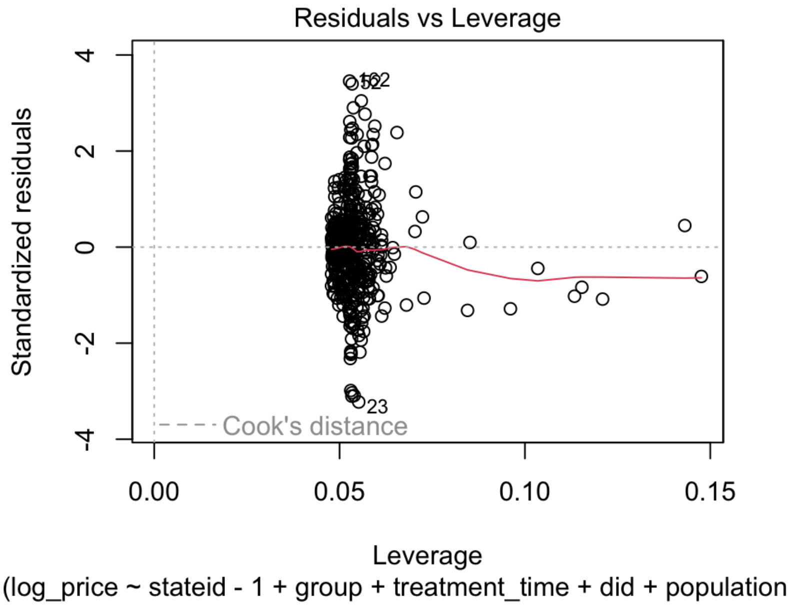
Map source: "Regional Transmission Organization (RTO) Map." 2015. https://energyfreedomco.org/f1-RTOmap.php

Residuals & QQ plots

Price Model: All Sectors



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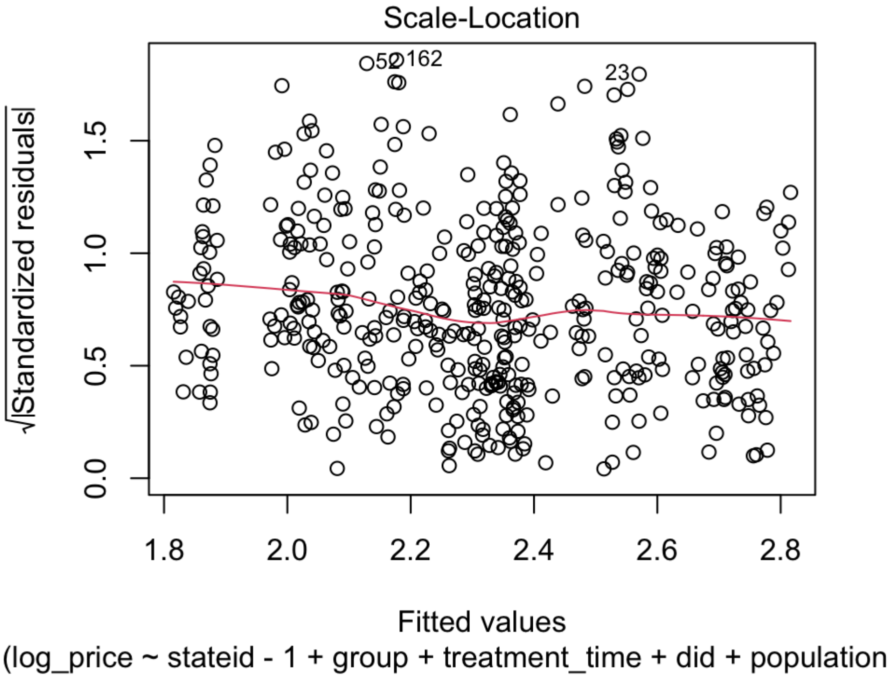
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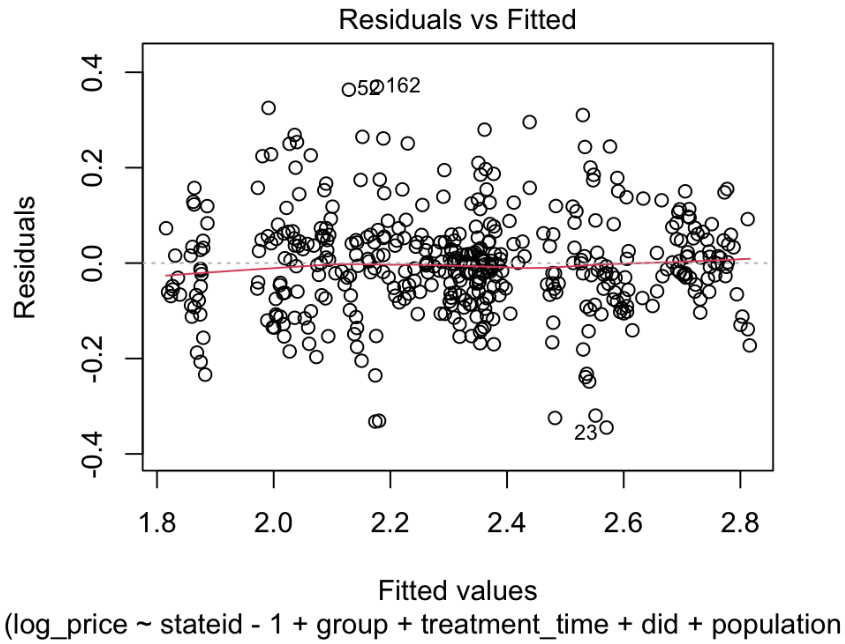
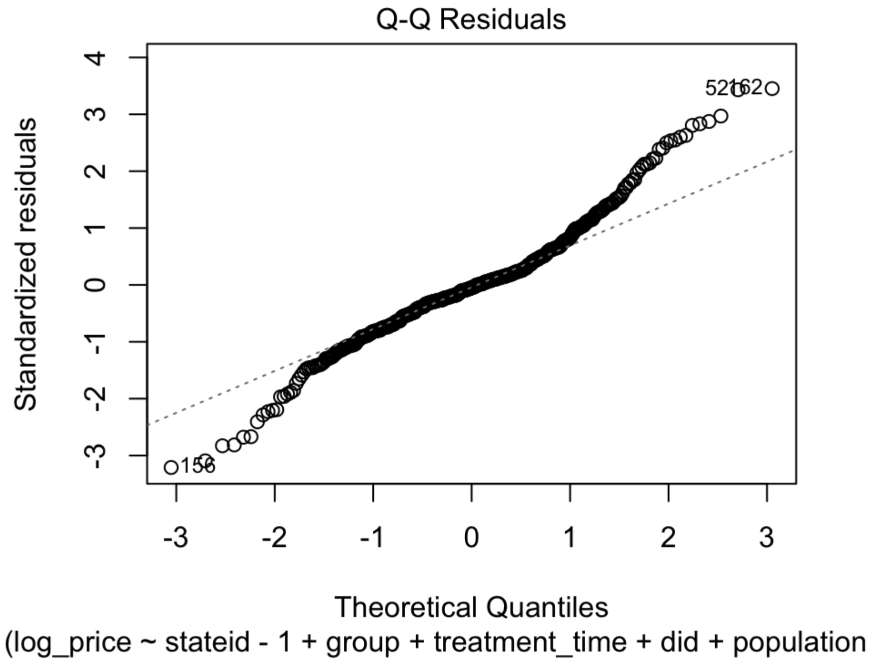
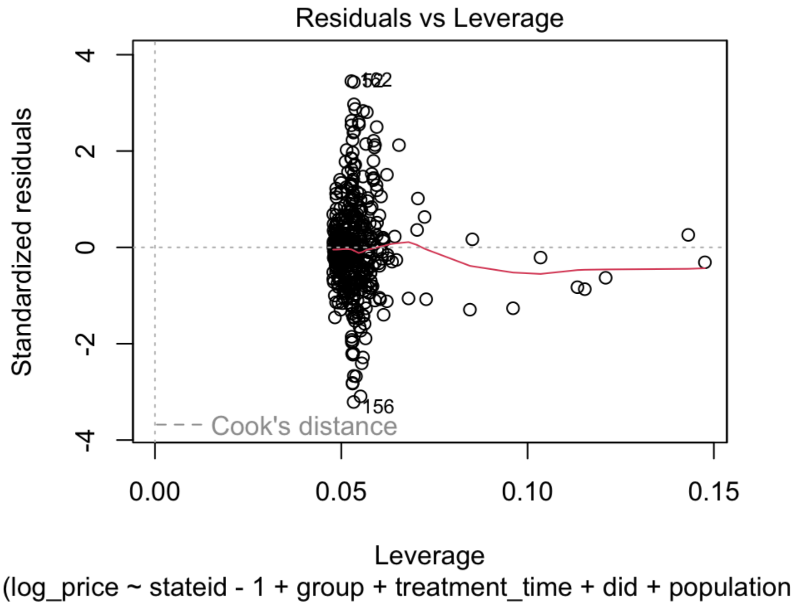
Price Model: Commercial Sector



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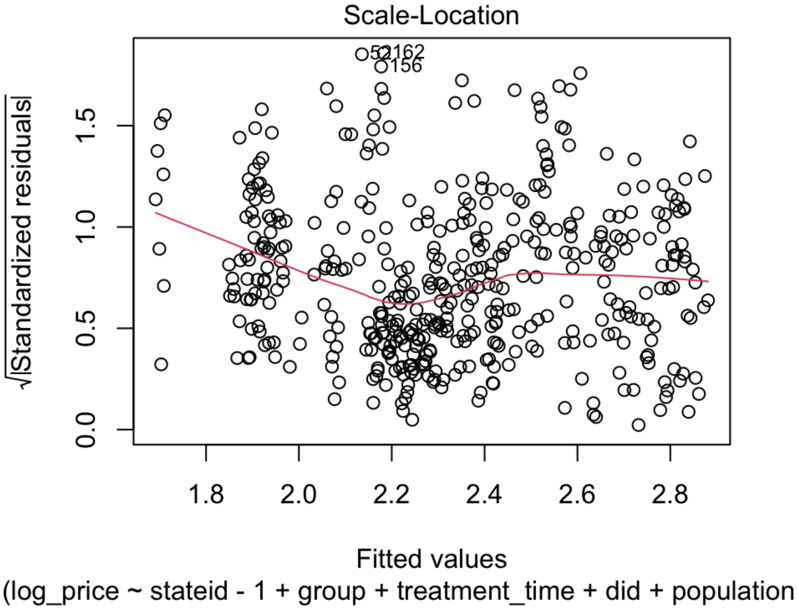
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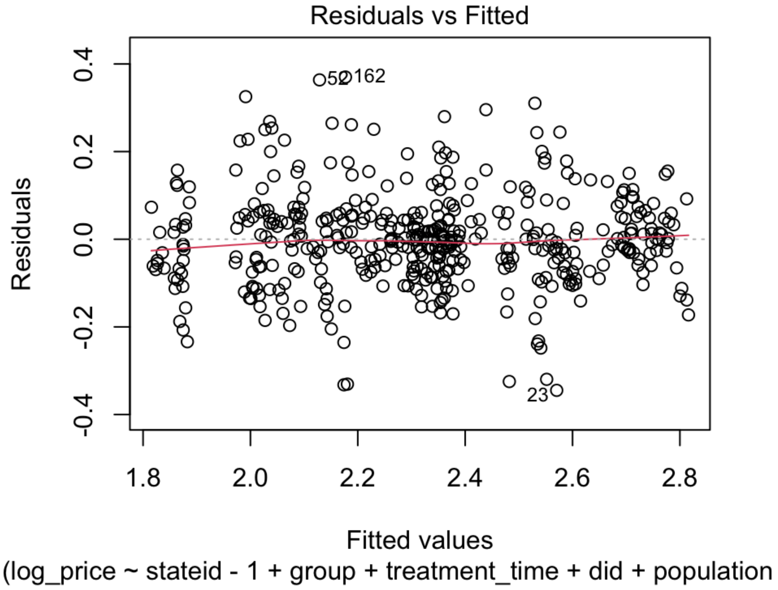
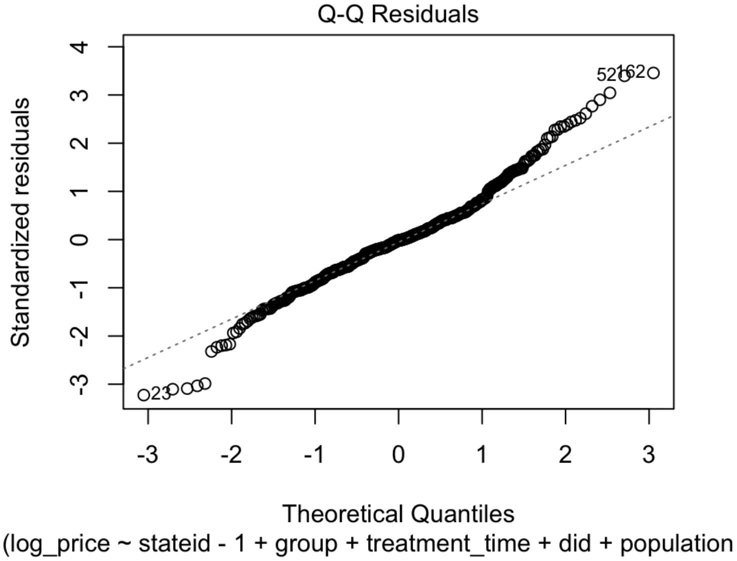
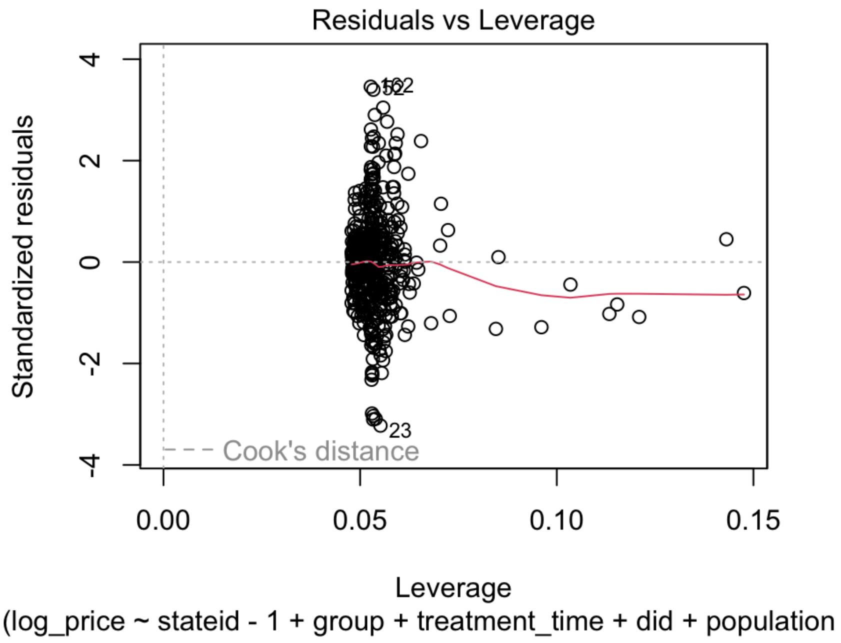
Price Model: Industrial Sector



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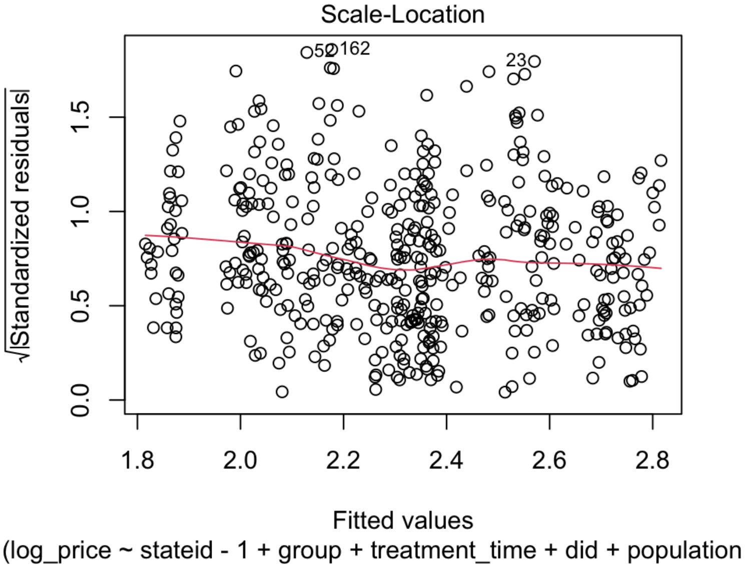
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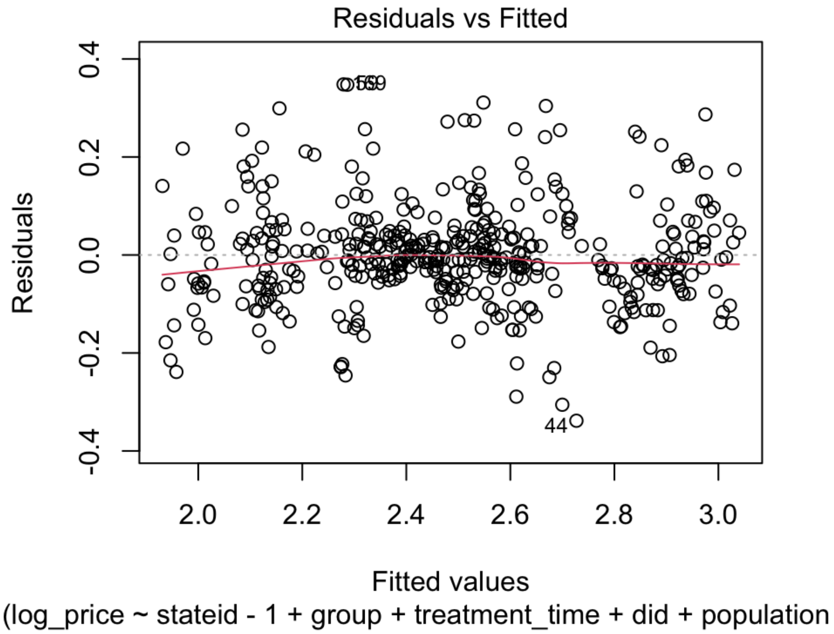

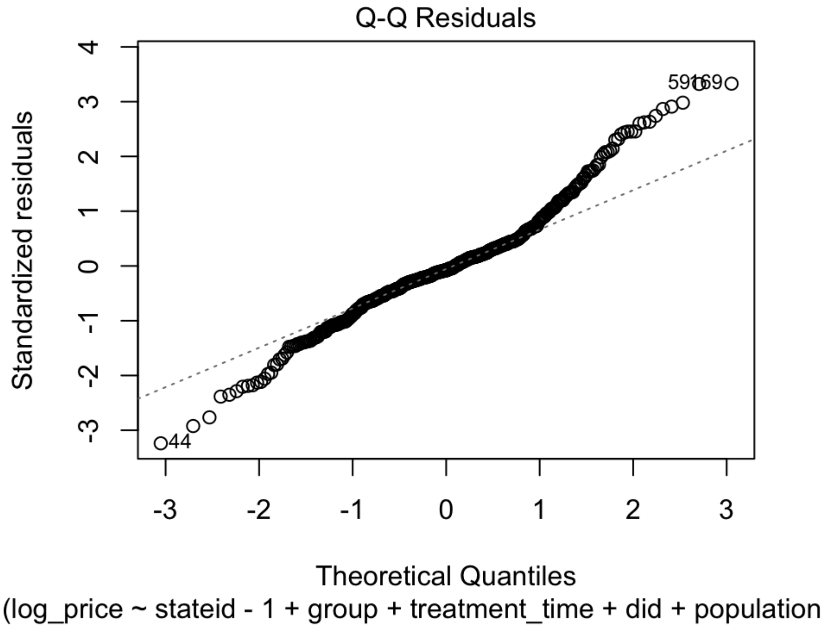

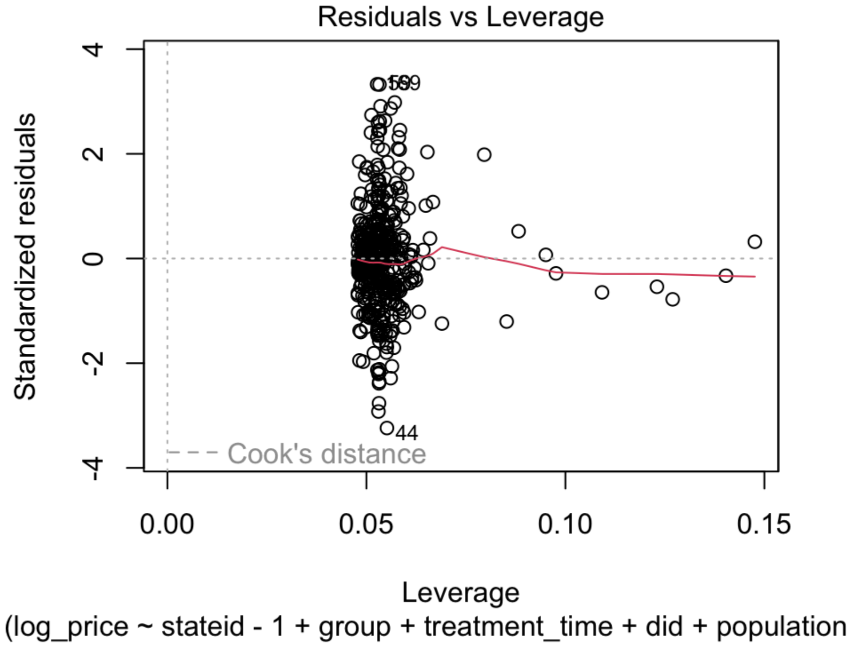
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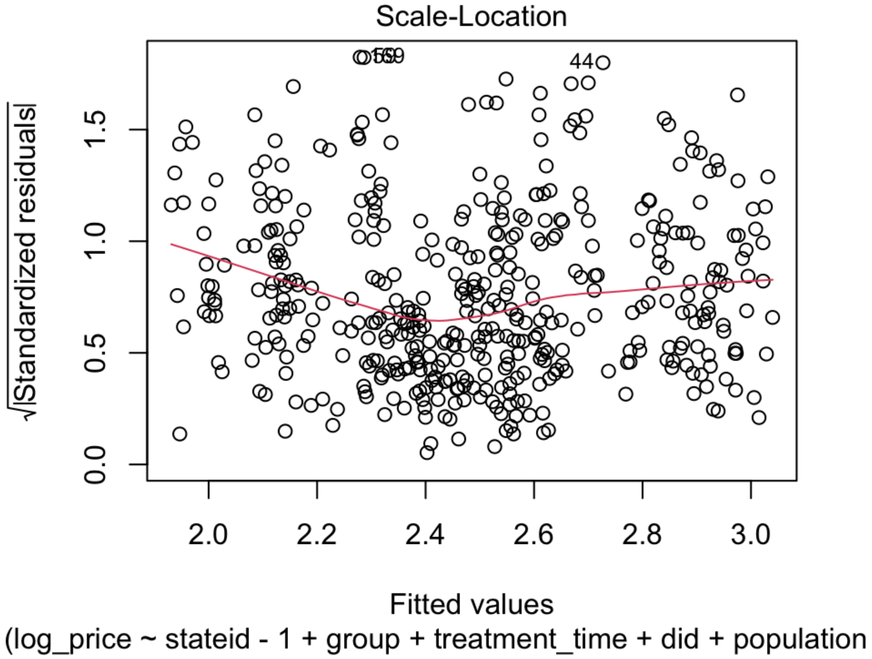
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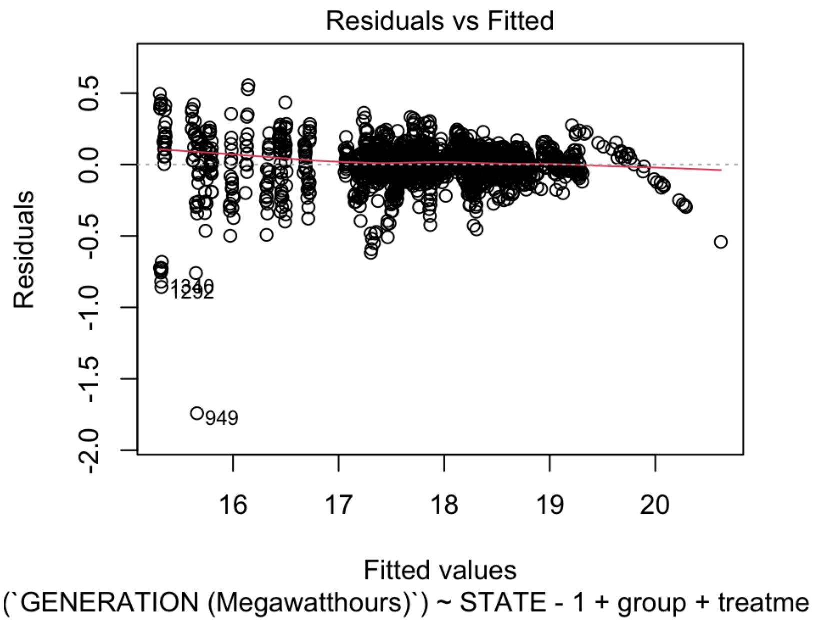
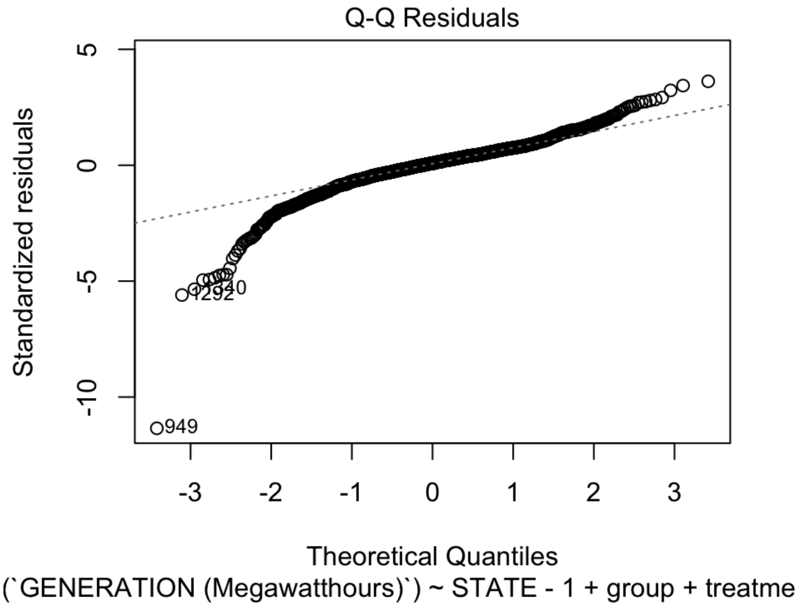
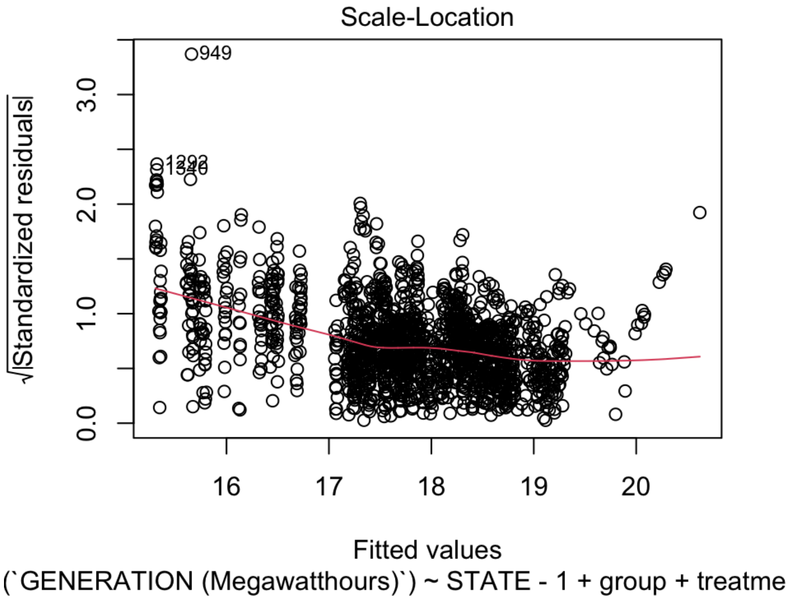
Leakage Model: Total Generation Ratio



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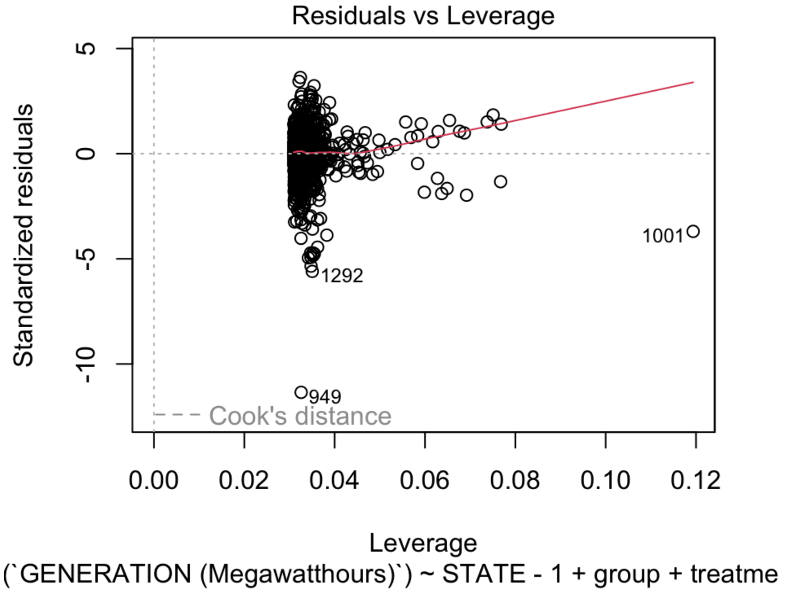
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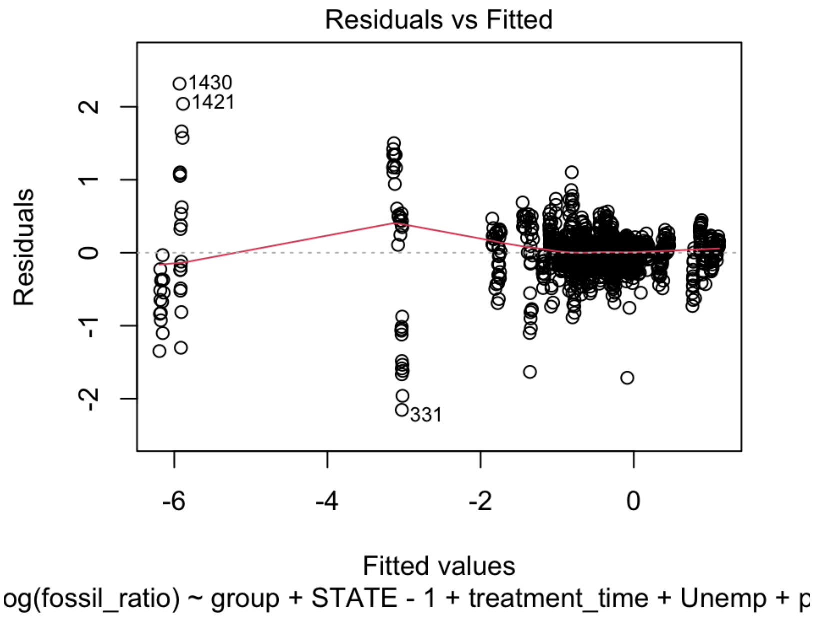
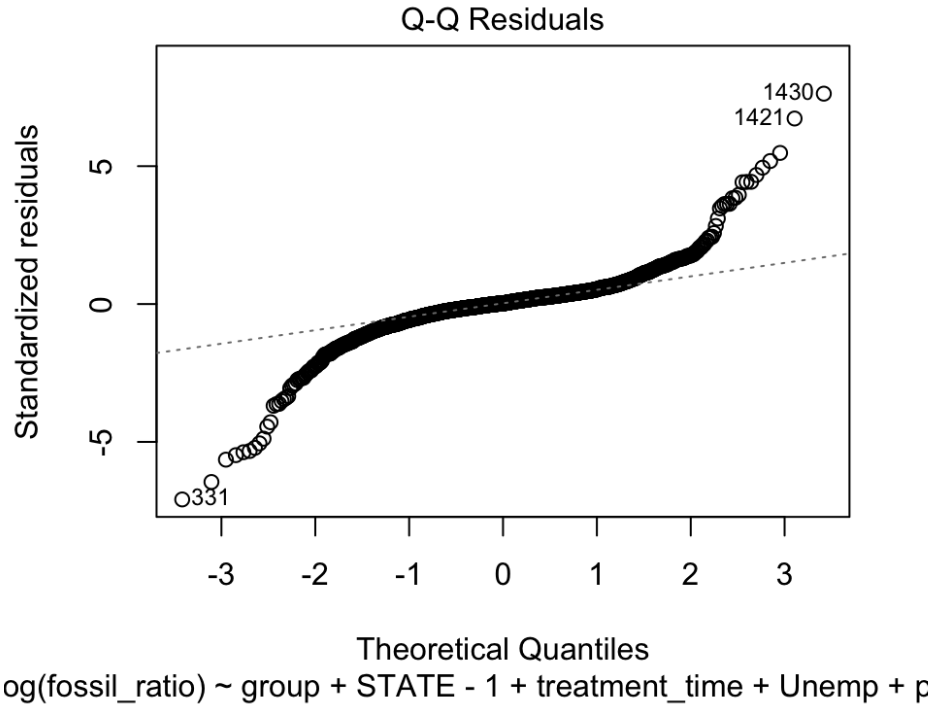
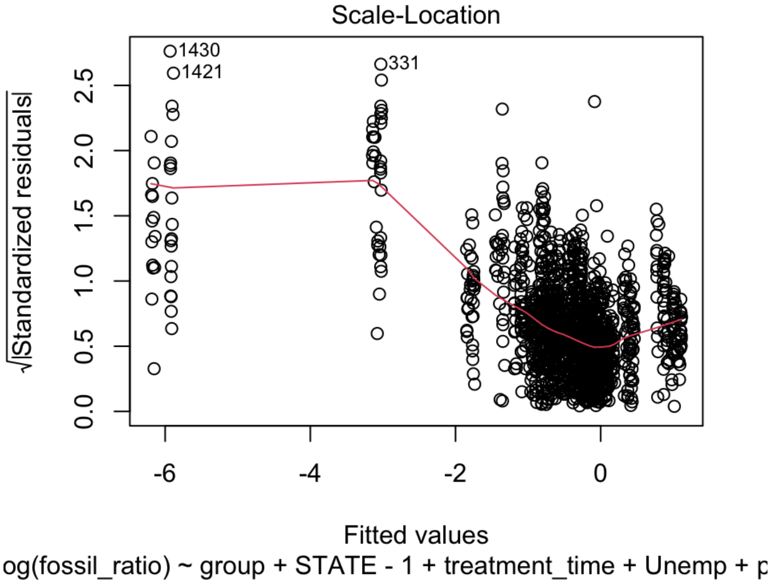
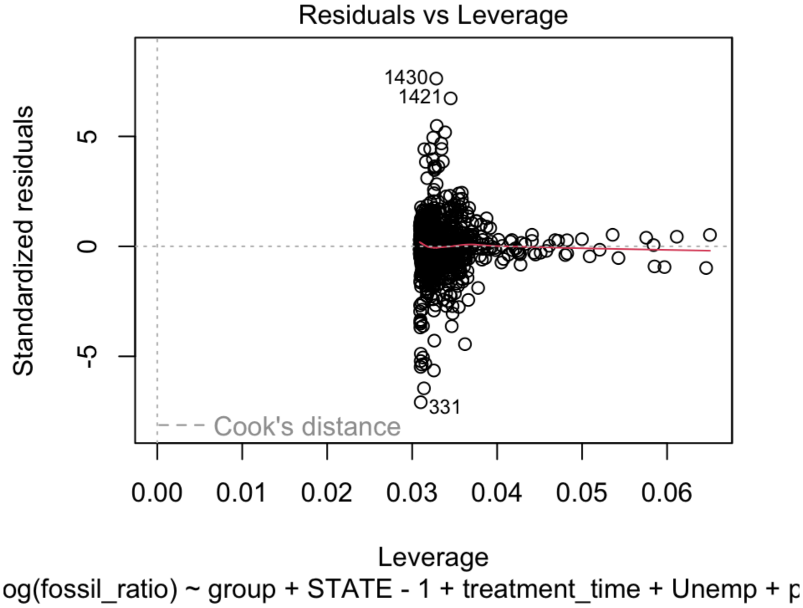
0.12
Leverage
(`GENERATION (Megawatthours)`) ~ STATE - 1 + group + treatme

Leakage Model: Fossil Fuels

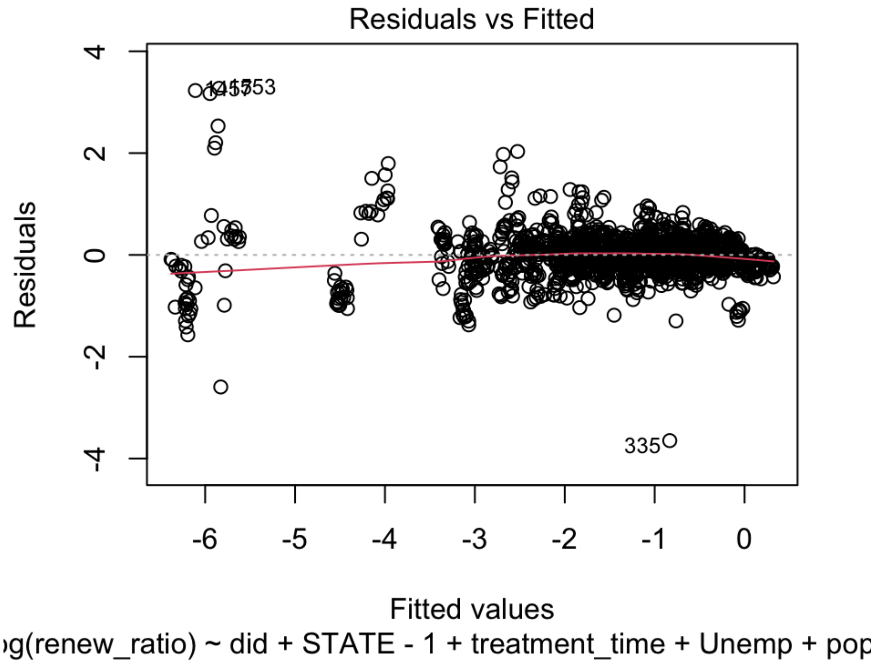


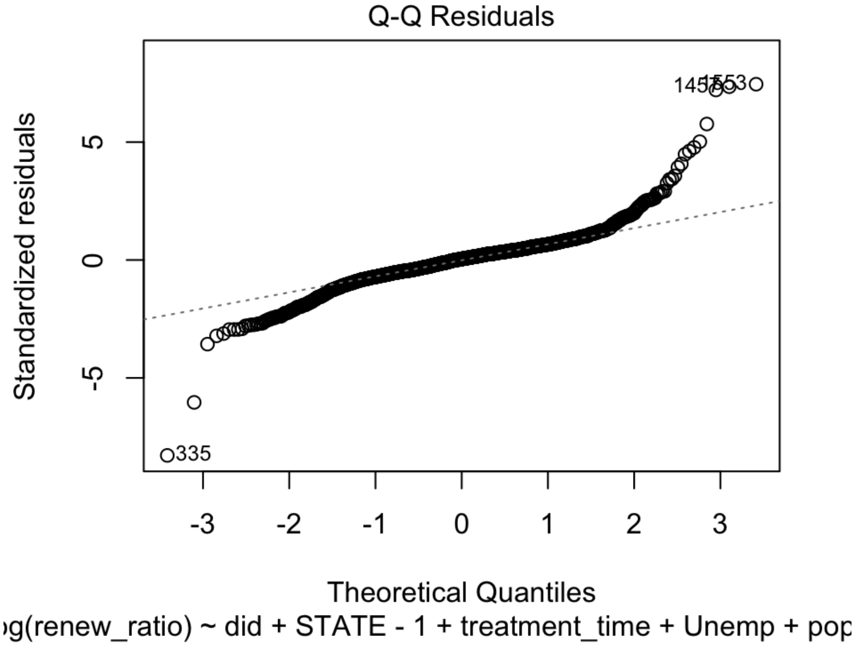


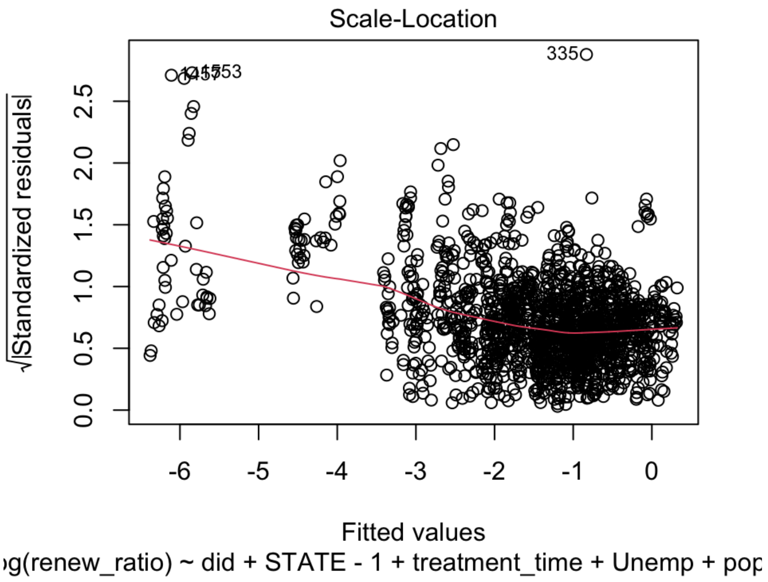

Scale-Location
√|Standardized residuals|
0.0
0.5
1.0
1.5
2.0
2.5
1430
1421
331
-6
-4
-2
0
Fitted values
og(fossil_ratio) ~ group + STATE - 1 + treatment_time + Unemp + p

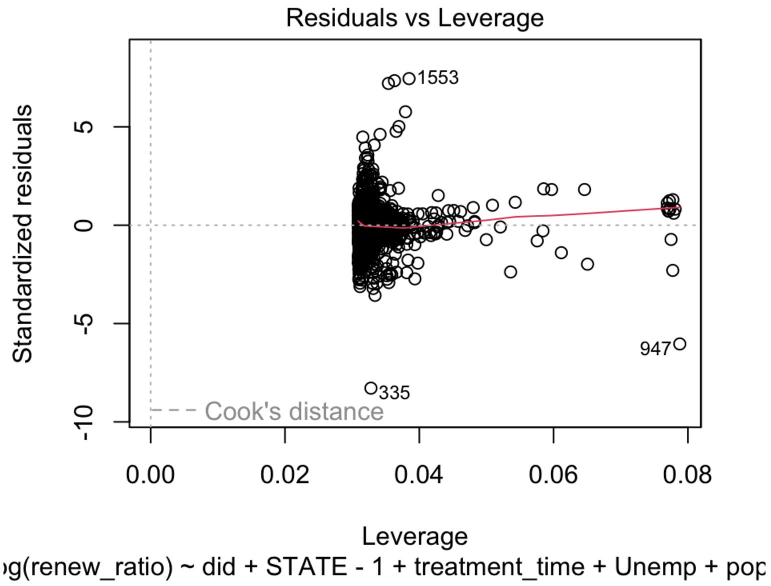

Residuals vs Leverage
Standardized residuals
5
0
-5
1430
1421
331
Cook's distance
0.00
0.01
0.02
0.03
0.04
0.05
0.06
Leverage
og(fossil_ratio) ~ group + STATE - 1 + treatment_time + Unemp + p

Leakage Model: Renewables






Scale-Location
335
1553
√|Standardized residuals|
0.0
0.5
1.0
1.5
2.0
2.5
-6
-5
-4
-3
-2
-1
0
Fitted values
og(renew_ratio) ~ did + STATE - 1 + treatment_time + Unemp + pop


Residuals vs Leverage
1553
947
335
Cook's distance
Standardized residuals
5
0
-5
-10
0.00
0.02
0.04
0.06
0.08
Leverage
og(renew_ratio) ~ did + STATE - 1 + treatment_time + Unemp + pop

Full Results Tables with State-fixed Effects

Price Models

Variable	Statistic	(1) ALL Sectors	(2) Commercial Sector	(3) Residential Sector	(4) Industrial Sector
stateidAL	std.error	(0.071)	(0.068)	(0.071)	(0.089)
stateidCT	estimate	2.632***	2.624***	2.813***	2.289***
stateidCT	std.error	(0.060)	(0.058)	(0.053)	(0.075)
stateidDE	estimate	2.216***	2.206***	2.402***	1.904***
stateidDE	std.error	(0.032)	(0.031)	(0.029)	(0.041)
stateidFL	estimate	2.010***	2.117***	2.388***	1.459***
stateidFL	std.error	(0.271)	(0.261)	(0.260)	(0.342)
stateidGA	estimate	1.969***	2.091***	2.289***	1.404***
stateidGA	std.error	(0.137)	(0.133)	(0.134)	(0.174)
stateidKY	estimate	1.768***	1.969***	2.096***	1.338***
stateidKY	std.error	(0.066)	(0.063)	(0.066)	(0.083)
stateidMA	estimate	2.564***	2.629***	2.764***	2.290***
stateidMA	std.error	(0.099)	(0.096)	(0.090)	(0.126)
stateidMD	estimate	2.208***	2.251***	2.401***	1.819***
stateidMD	std.error	(0.088)	(0.085)	(0.080)	(0.111)
stateidME	estimate	2.424***	2.438***	2.643***	2.045***
stateidME	std.error	(0.035)	(0.034)	(0.032)	(0.044)
stateidMO	estimate	1.907***	1.919***	2.161***	1.483***
stateidMO	std.error	(0.086)	(0.083)	(0.086)	(0.108)
stateidMS	estimate	2.012***	2.143***	2.248***	1.562***
stateidMS	std.error	(0.050)	(0.049)	(0.051)	(0.064)

stateidNC	estimate	1.939***	1.973***	2.276***	1.421***
stateidNC	std.error	(0.135)	(0.131)	(0.132)	(0.171)
stateidNJ	estimate	2.396***	2.457***	2.638***	2.048***
stateidNJ	std.error	(0.130)	(0.125)	(0.117)	(0.164)
stateidNY	estimate	2.448***	2.689***	2.876***	1.433***
stateidNY	std.error	(0.277)	(0.268)	(0.256)	(0.351)
stateidPA	estimate	2.064***	2.188***	2.481***	1.547***
stateidPA	std.error	(0.183)	(0.176)	(0.167)	(0.231)
stateidRI	estimate	2.595***	2.562***	2.730***	2.394***
stateidRI	std.error	(0.036)	(0.034)	(0.032)	(0.045)
stateidSC	estimate	1.974***	2.085***	2.317***	1.452***
stateidSC	std.error	(0.070)	(0.068)	(0.070)	(0.089)
stateidTN	estimate	1.936***	2.107***	2.149***	1.451***
stateidTN	std.error	(0.092)	(0.089)	(0.092)	(0.116)
stateidVA	estimate	1.934***	1.934***	2.249***	1.494***
stateidVA	std.error	(0.117)	(0.113)	(0.109)	(0.148)
stateidVT	estimate	2.481***	2.536***	2.649***	2.136***
stateidVT	std.error	(0.029)	(0.028)	(0.027)	(0.037)
treatment_time	estimate	0.342***	0.328***	0.347***	0.278***
treatment_time	std.error	(0.022)	(0.021)	(0.020)	(0.027)
Diff in Diff	estimate	-0.059*	-0.111***	-0.023	-0.066*
Diff in Diff	std.error	(0.024)	(0.023)	(0.023)	(0.031)
population	estimate	0.000	0.000	0.000	0.000
population	std.error	(0.000)	(0.000)	(0.000)	(0.000)

Unemp	estimate	-0.018***	-0.016***	-0.023***	-0.006
Unemp	std.error	(0.003)	(0.003)	(0.003)	(0.004)
Num.Obs.		440	440	440	440
R2		0.998	0.998	0.998	0.995
R2 Adj.		0.998	0.998	0.998	0.995
AIC		-637.5	-668.4	-689.1	-430.2
BIC		-535.4	-566.2	-586.9	-328.0
Log.Lik.		343.772	359.205	369.527	240.085
RMSE		0.11	0.11	0.10	0.14

Leakage Models

Variable	Statistic	(1) Total in-state Production	(2) Test on Fossil Fuels	(3) Test on Renewables
STATEAL	estimate	18.236***	-0.060	-0.388***
STATEAL	std.error	(0.042)	(0.075)	(0.109)
STATEAR	estimate	17.549***	-0.297***	-0.727***
STATEAR	std.error	(0.034)	(0.066)	(0.095)
STATEAZ	estimate	18.142***	-0.253**	-0.211+
STATEAZ	std.error	(0.042)	(0.082)	(0.119)
STATECA	estimate	19.295***	-1.384***	0.775
STATECA	std.error	(0.206)	(0.348)	(0.505)
STATECO	estimate	17.519***	-0.200**	-2.250***
STATECO	std.error	(0.037)	(0.074)	(0.107)
STATECT	estimate	17.300***	5.295***	-0.452***
STATECT	std.error	(0.036)	(0.081)	(0.103)
STATEDE	estimate	15.765***	5.534***	-5.702***
STATEDE	std.error	(0.031)	(0.076)	(0.140)
STATEFL	estimate	18.452***	-0.451*	-1.064***
STATEFL	std.error	(0.091)	(0.180)	(0.261)
STATEGA	estimate	18.106***	-0.526***	-0.737***
STATEGA	std.error	(0.054)	(0.105)	(0.152)
STATEIA	estimate	17.442***	-0.290***	-1.268***
STATEIA	std.error	(0.032)	(0.063)	(0.092)
STATEID	estimate	16.248***	-3.108***	-0.643***
STATEID	std.error	(0.031)	(0.061)	(0.088)

STATEIL	estimate	18.593***	-0.705***	0.285
STATEIL	std.error	(0.068)	(0.135)	(0.195)
STATEIN	estimate	18.070***	-0.001	-3.994***
STATEIN	std.error	(0.045)	(0.084)	(0.122)
STATEKS	estimate	17.446***	-0.255***	-0.901***
STATEKS	std.error	(0.032)	(0.063)	(0.092)
STATEKY	estimate	17.818***	-0.046	-2.911***
STATEKY	std.error	(0.042)	(0.073)	(0.106)
STATELA	estimate	17.904***	-0.213**	-1.295***
STATELA	std.error	(0.042)	(0.075)	(0.109)
STATEMA	estimate	17.414***	5.345***	-1.765***
STATEMA	std.error	(0.047)	(0.095)	(0.129)
STATEMD	estimate	17.458***	5.130***	-1.022***
STATEMD	std.error	(0.041)	(0.090)	(0.119)
STATEME	estimate	16.499***	5.095***	-0.695***
STATEME	std.error	(0.032)	(0.077)	(0.091)
STATEMI	estimate	18.262***	-0.426***	-0.666***
STATEMI	std.error	(0.058)	(0.114)	(0.165)
STATEMN	estimate	17.520***	-0.742***	-1.012***
STATEMN	std.error	(0.038)	(0.075)	(0.109)
STATEMO	estimate	17.875***	-0.197*	-1.568***
STATEMO	std.error	(0.041)	(0.081)	(0.118)
STATEMS	estimate	17.381***	-0.383***	-1.338***
STATEMS	std.error	(0.036)	(0.069)	(0.100)
STATEMT	estimate	17.035***	0.098	-0.166+

STATEMT	std.error	(0.030)	(0.060)	(0.087)
STATENC	estimate	18.076***	-0.659***	-0.543***
STATENC	std.error	(0.054)	(0.104)	(0.150)
STATEND	estimate	17.219***	0.821***	-1.146***
STATEND	std.error	(0.029)	(0.056)	(0.082)
STATENE	estimate	17.110***	-0.282***	-0.828***
STATENE	std.error	(0.030)	(0.058)	(0.084)
STATENH	estimate	16.732***	5.467***	0.153+
STATENH	std.error	(0.031)	(0.076)	(0.088)
STATENJ	estimate	17.850***	4.975***	-0.411**
STATENJ	std.error	(0.056)	(0.109)	(0.153)
STATENM	estimate	17.242***	0.352***	-2.765***
STATENM	std.error	(0.032)	(0.064)	(0.093)
STATENV	estimate	17.165***	-0.146*	-1.609***
STATENV	std.error	(0.034)	(0.066)	(0.096)
STATENY	estimate	18.805***	5.036***	0.305
STATENY	std.error	(0.111)	(0.194)	(0.285)
STATEOH	estimate	18.124***	-0.413***	-1.648***
STATEOH	std.error	(0.065)	(0.125)	(0.182)
STATEOK	estimate	17.733***	-0.015	-1.969***
STATEOK	std.error	(0.035)	(0.067)	(0.098)
STATEOR	estimate	17.596***	-1.457***	0.051
STATEOR	std.error	(0.036)	(0.071)	(0.104)
STATEPA	estimate	18.743***	-0.249+	0.067
STATEPA	std.error	(0.068)	(0.134)	(0.194)

STATERI	estimate	15.696***	5.799***	-5.940***
STATERI	std.error	(0.033)	(0.077)	(0.094)
STATESC	estimate	17.938***	-0.782***	-0.066
STATESC	std.error	(0.041)	(0.074)	(0.108)
STATESD	estimate	15.975***	-1.142***	-0.523***
STATESD	std.error	(0.029)	(0.057)	(0.082)
STATETN	estimate	17.793***	-0.767***	-0.683***
STATETN	std.error	(0.045)	(0.083)	(0.121)
STATETX	estimate	18.310***	-0.347	-0.643+
STATETX	std.error	(0.125)	(0.233)	(0.338)
STATEUT	estimate	17.369***	0.334***	-2.740***
STATEUT	std.error	(0.031)	(0.062)	(0.090)
STATEVA	estimate	17.696***	-0.940***	-0.909***
STATEVA	std.error	(0.047)	(0.092)	(0.133)
STATEVT	estimate	15.364***	-5.973***	-0.185*
STATEVT	std.error	(0.030)	(0.059)	(0.086)
STATEWA	estimate	18.101***	-1.899***	0.376**
STATEWA	std.error	(0.045)	(0.087)	(0.126)
STATEWI	estimate	17.660***	-0.469***	-1.281***
STATEWI	std.error	(0.040)	(0.078)	(0.114)
STATEWV	estimate	18.030***	0.904***	-2.607***
STATEWV	std.error	(0.034)	(0.065)	(0.095)
STATEWY	estimate	17.492***	1.040***	-1.860***
STATEWY	std.error	(0.030)	(0.058)	(0.085)
treatment_time	estimate	0.120***	-0.090***	0.496***

treatment_time	std.error	(0.011)	(0.021)	(0.030)
Diff in diff	estimate	-0.157***	-0.164***	-0.208***
Diff in Diff	std.error	(0.020)	(0.039)	(0.059)
Unemp	estimate	-0.004+	0.012*	-0.044***
Unemp	std.error	(0.003)	(0.005)	(0.007)
pop	estimate	-6.765e-08***	1.18E-08	-4.813e-08***
pop	std.error	(-6.296e-10)	(9.576E09)	(1.389E08)
Num.Obs.		1584	1584	1564
R2		1.000	0.935	0.950
R2 Adj.		1.000	0.933	0.948
AIC		55073.0	824.4	1978.0
BIC		55362.8	1108.8	2261.8
Log.Lik.		722.639	-359.178	-936.014
RMSE		0.15	0.30	0.44