Not for Publication - Reviewer Appendix

This appendix presents the results of a number of robustness checks including controlling for changes in power plant ownership, analyzing the impact of fuel-switching on the emissions of other pollutants, using intra-month variation to identify the impact of fuel switching, results for non-fuel switching power plants in NYC as a placebo test and using fuel price spread deciles, rather than quartiles.

1 Power plant ownership

Astoria and Ravenswood were both sold during the study period. Reliant sold Astoria to a subsidiary of U.S. Power Generating Company. The transaction closed on June 1, 2007. We create a dummy variable equal to 0 when Astoria is owned by Reliant and 1 when it is owned by U.S. Power. We then re-estimate the baseline regression, the natural gas regression and the SO_2 emissions including the ownership dummy variable. Figure 1 describes the results of those regressions for Astoria and figure 2 describes the results for Ravenswood.

2 Within power plant emissions reductions

We observe significant reductions in emissions rates as the fuel price spread increases. We now analyze stack level generation by fuel type to determine the source of those reductions. Most power plants consist of multiple generating units on a single site. Astoria is made up of four separate generating units, one that is only capable of burning natural gas and three others that list fuel oil as their primary fuel and natural gas as the secondary fuel. Ravenswood has 4 large and 15 small combustion turbines each of which list some combination of natural gas, fuel oil or kerosene as their primary and secondary fuel. Table 1 summarizes generation in megawatts from each fuel source at each generating station at Astoria. Three of the units at Astoria move from generating more than 90% of their electricity from oil to producing between 60%-70% from natural gas.

Table 2 summarizes generation in megawatts from each fuel source at each generating station at Ravenswood. As with Astoria, the units are burning upwards of 90% oil in spread quartile 1. As the fuel price spread increases these units shift to using more natural gas, although there is more variance in the level of generation than at Astoria. Unit 20 produces 70% of its electricity from natural gas while unit 30 uses oil and natural gas in roughly equal proportion. The natural gas unit at Ravenswood continues to generate at the same level. Most of the response to fuel prices in both power plants appears to come from individual units switching fuels, rather than changes in the way the units are dispatched.

3 Real Time Pricing Impacts on Other Pollutants

The text focuses on the CO_2 emissions impact of real time pricing. In this appendix we also estimate the impact of real time pricing on SO_2 and NO_X emissions. The results are largely consistent with those reported for CO_2. The largest environmental benefit of real time pricing comes from peak demand hours during the summer months in fuel price spread quartile 1. Table 4 describes the reductions in NO_x emissions and table 3 reports reductions in SO_2. The pattern of emissions reductions is consonant with those reported for CO_2. The only difference is the level of marginal emissions intensity, which differs by pollutant.

Valuing these benefits is somewhat more difficult than valuing the environmental benefits of CO2 emissions reductions because they fall under various EPA transferable discharge markets. To provide a back of the envelope calculation for the benefits of real time pricing we value the reductions at the marginal costs as estimated by the NY State Department of Environmental Conservation. The NESCAUM uses a marginal damage estimate $20,167 per ton of SO_2 emissions when valuing benefits of environmental regulation.[1] Estimated by adding the hourly emissions reductions of RTP

[1]This figure is based on a Northeast States for Coordinated Air Use Management (NESCAUM) study of local damages from air pollution using EPA BenMAP. The study to assess the marginal damage of sulfur pollution, and its sulfur reduction benefit figures, have been cited in NYS regulation phasing out the use of residual fuels for heating in New York City. We cite those figures here.

across each hour and then across the year, RTP in New York City would reduce emissions by 6.7 million pounds per year during spread quartile 1 and around 1.3 million pounds in the other spread quartiles. That represents benefits of $80 million during spread quartile 1 and $56-58 million in quartiles 2-4.

These numbers only represent a true benefit to the extent that emissions are under the capped level. When the cap binds reductions in emissions in New York City will lead to the sale of permits and an increase in emissions elsewhere. Because the cap is not currently binding reductions in SO2 emissions represent a potential net benefit to society.

4 Other pollutants

The results presented thus far have focused on the impact of fuel switching on SO_2 emissions, but the EPA CEM's data includes information on NO_x and CO_2 emissions as well. We now turn to estimating the impact of fuel switching on emissions of those pollutants. We simply re-estimate the baseline specification substituting emissions of CO_2 and NO_x for SO_2 as the dependent variable. As before, the β coefficient vector can be interpreted as the marginal emissions in a spread quartile and NYC load decile. Figure 3 reports results for CO_2 emissions and figure 4 reports results for NO_x emissions. The results are consistent, but the differences between quartile 1 and quartiles 2-4 are smaller. This is consistent with smaller difference in pollution content described in Table 2. The results for CO_2 may be of particular interest, as they represent true net benefits from fuel switching, not transfers between participants in a cap-and-trade market.

5 Intra-month variation

The results presented thus far have relied on short run variation in relative fuel price spreads controlling for seasonality using month fixed effects and long run trends using year fixed effects. It may be possible to identify the same effect off intra-month variation using month-by-year fixed effects. In this specification all the identification on the β coefficients would come from intra-month variation in fuel price spread quartiles. Unfortunately, the relative fuel prices vary slowly over time. Only 32 of the 72 months in dataset experience multiple spread quartiles. Only 4 months experience three spread quartiles and no month contains all four. This source of identification could be useful if long run trends in fuel prices or dispatch patterns are changing over time or changing in non-linear ways. We estimate:

$$Pollution_{f,h} = +\beta_{q,d} * Gen_{f,h} * SpreadQuartile_h * NYCLoadDecile_h + \omega W_h + \theta + \epsilon, \qquad (1)$$

where θ is a set of 72 month of sample fixed effects. Figure 5 displays the results for NYC (top panel), Astoria (middle panel) and Ravenswood (bottom panel) where the coefficients are estimated off intra-month variation.

6 Other power plants in NYC

We include the emissions levels of several other power plants that our methodology identifies as primarily or exclusively natural gas-fired as a placebo test. If the results we have identified are a causal result of changes in fuel price spreads, then there should be no difference in the marginal emissions of SO_2 across fuel price quartiles. We focus on three of the largest power plants in NYC as described in Table 3 in the of the paper. Figure 6 describes the results for Arthur Kill in the top panel, Astoria Energy (a different power plant on the same site as Astoria Generating Station) in the middle panel and East River in the bottom panel. The results are consistent with the hypothesis that changes in relative fuel prices are leading to large changes in marginal emissions rates. In both cases the small quantity of oil fired generation comes online at high demand levels in fuel price spread quartile 1.

7 Fuel price spread deciles

Finally, we break the fuel price spread,[2] into deciles rather than quartiles. The results of these regressions are presented in Figure 7 for New York City and each of the fuel switching power plants. There are differences between emissions intensities across the first 3 spread deciles, but the remaining 7 deciles are grouped together. The first three spread deciles are decreasing in emissions intensity as the spread in fuel prices go. These results provide validation for the decision to evaluate the impact of fuel switching using fuel price spread quartiles, although defining spread deciles we can highlight the highly non-linear impact of relative fuel prices.

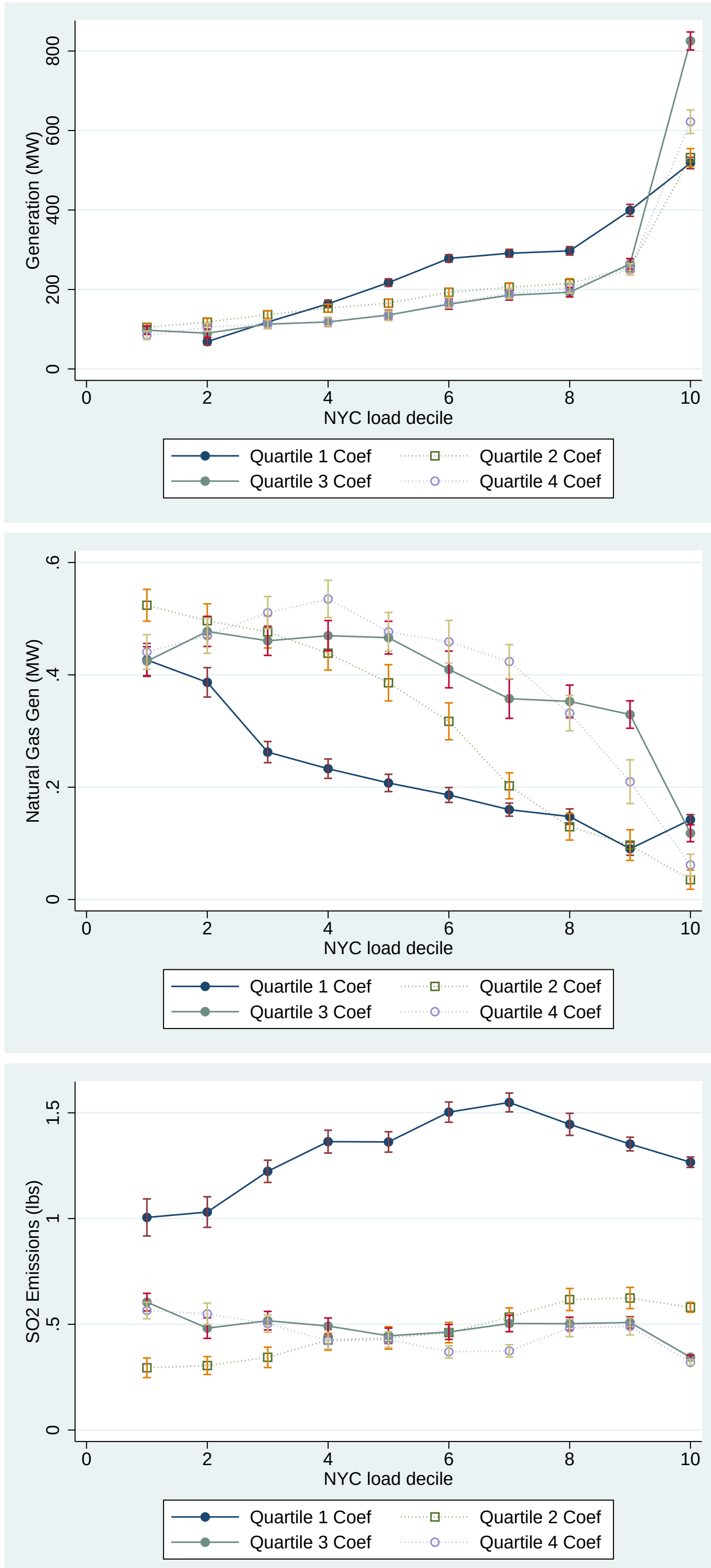
Table 1: Stack output by fuel: Astoria

Stack	Fuel	Q1 (1)	Q2-4 (2)	Q1 (3)	Q2-4 (4)
20	Distillate/Residual	0.0	0	0.00	0.00
20	Natural Gas	100.7	49.2	1.00	1.00
30	Distillate/Residual	1,406.7	335.7	0.91	0.31
30	Natural Gas	141.3	752.8	0.09	0.69
40	Distillate/Residual	1,560.6	334.5	0.91	0.31
40	Natural Gas	163.2	732.6	0.09	0.69
50	Distillate/Residual	1,935.4	395.6	0.95	0.37
50	Natural Gas	99.8	680.3	0.05	0.63

Note: The table reports average generation level (in MW) and fraction of total generation by fuel type for each of 4 generators at Astoria.

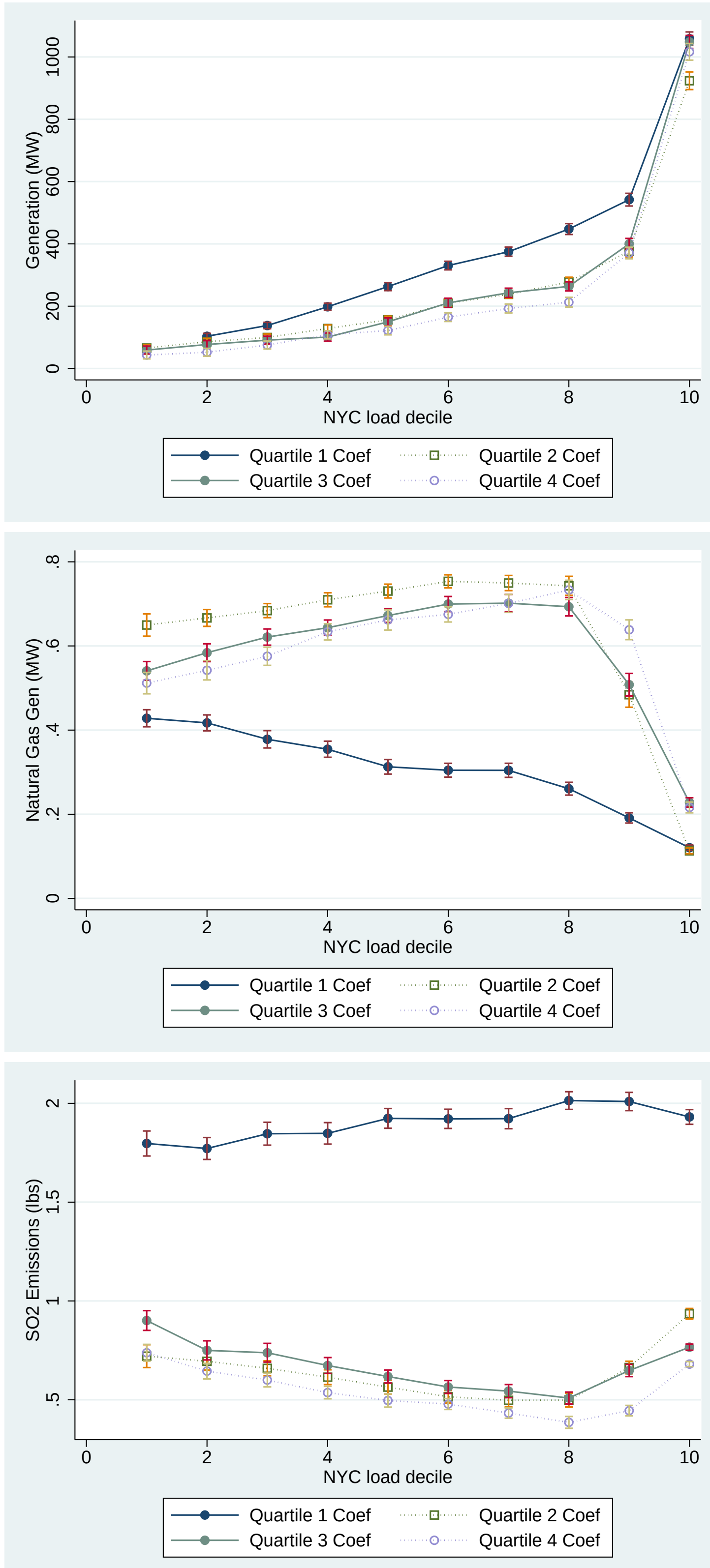
[2] Defined as *diesel fuel* − *natural gas* price where both prices are measured in mmBTU.

Figure 1: Astoria ownership impact change: Pollution emissions by fuel price spread and NYC load level



Note: The results of regressions estimating the average generation level (top level), natural gas generation (middle panel) and marginal SO_2 emissions (bottom panel) from a one megawatt increase in generation conditional on weather, month, and year fixed effects for Astoria Generating Station. This specification includes control for plant owner. The vertical axis is the level of generation measured in megawatts. The vertical bars represent the 95% confidence interval for the coefficient estimate. All regressions include robust standard errors. This corrects for both intra-power plant correlation across time and possible serial correlation in the error term.

Figure 2: Ravenswood ownership impact change: Pollution emissions by fuel price spread and NYC load level



Note: The results of regressions estimating the average generation level (top level), natural gas generation (middle panel) and marginal SO_2 emissions (bottom panel) from a one megawatt increase in generation conditional on weather, month, and year fixed effects for Ravenswood Generating Station. This specification includes control for plant owner. The vertical axis is the level of generation measured in megawatts. The vertical bars represent the 95% confidence interval for the coefficient estimate. All regressions include robust standard errors. This corrects for both intra-power plant correlation across time and possible serial correlation in the error term.

Table 2: Stack output by fuel: Ravenswood

Stack	Fuel	Q1 (1)	Q2-4 (2)	Q1 (3)	Q2-4 (4)
10	Distillate/Residual	1497.5	346.2	0.91	0.30
10	Natural Gas	152.0	792.6	0.09	0.70
20	Distillate/Residual	1546.5	266.3	0.92	0.35
20	Natural Gas	141.9	500.2	0.08	0.65
30	Distillate/Residual	2126.1	914.6	0.93	0.48
30	Natural Gas	165.7	977.3	0.07	0.52
CT's	Distillate/Residual	0.0	0.0	.	.
CT's	Natural Gas	0.0	14.3	0.00	1.00
UCC001	Distillate/Residual	0.0	0.0	0.00	0.00
UCC001	Natural Gas	2330.3	2224.3	1.00	1.00

Note: The table reports average generation level (in MW) and fraction of total generation by fuel type for each of 4 main generators at Ravenswood. The 15 small combustion turbines are aggregated in the CT's rows.

Table 3: Estimated SO_2 Emissions Reductions Under Real Time Pricing

	No Summer				Summer			
	Spread Quartile							
Hour	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
6	-759	-175	-125	-92	-1090	-125	-125	-92
7	-891	-179	-155	-140	-1168	-168	-155	-140
8	-1000	-196	-208	-199	-1230	-240	-208	-199
9	-1097	-213	-240	-233	-1302	-298	-240	-233
10	-1137	-218	-247	-244	-1294	-316	-247	-244
11	-1160	-215	-245	-254	-1288	-319	-245	-254
12	-1147	-212	-239	-254	-1253	-317	-239	-254
13	-1132	-210	-237	-260	-1213	-315	-237	-260
14	-1113	-203	-232	-255	-1207	-309	-232	-255
15	-1104	-202	-232	-261	-1200	-307	-232	-261
16	-1176	-209	-245	-277	-1260	-321	-245	-277
17	-1322	-223	-261	-291	-1400	-333	-261	-291
18	-1309	-228	-263	-282	-1384	-326	-263	-282
19	-1243	-229	-254	-261	-1330	-317	-254	-261
20	-1160	-226	-223	-228	-1270	-303	-223	-228
21	-1039	-200	-192	-186	-1169	-259	-192	-186

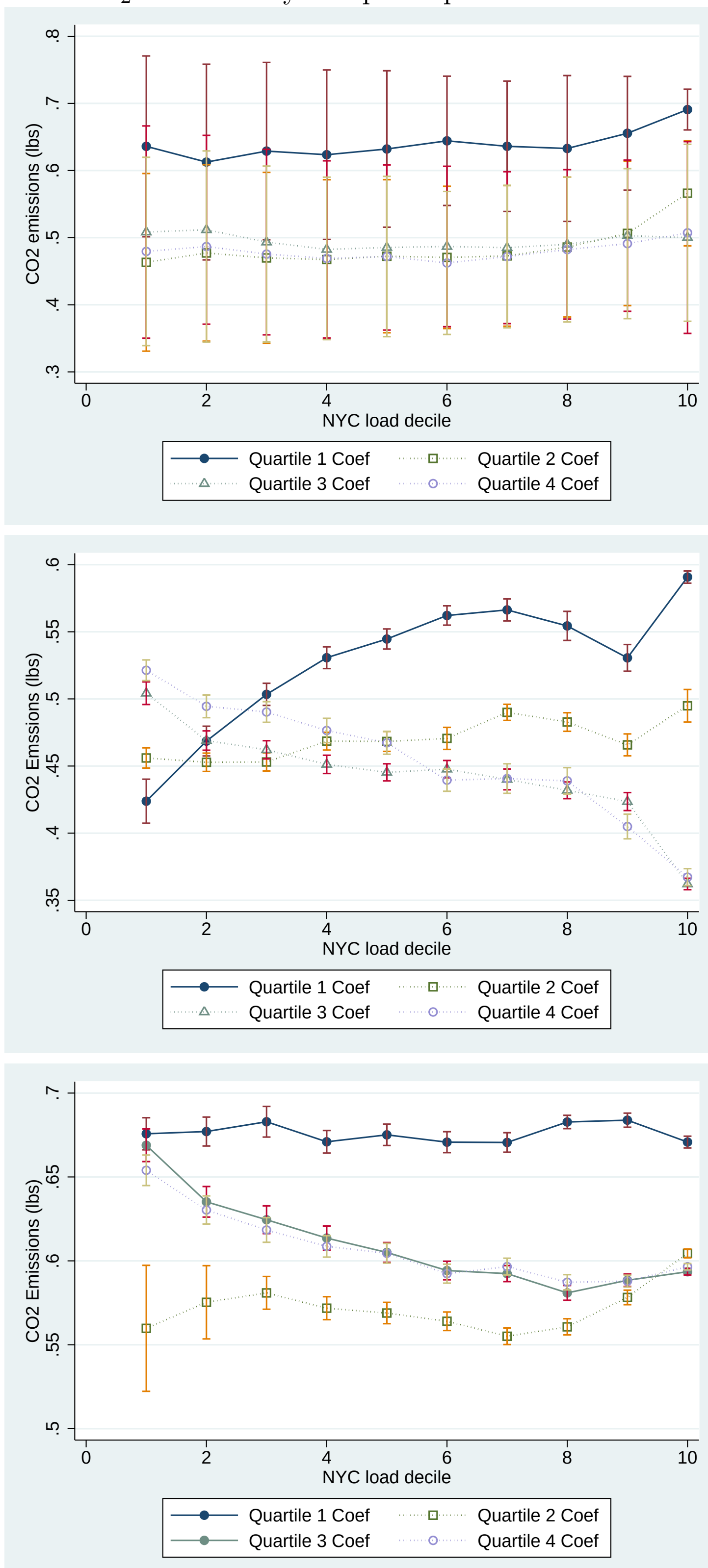
Note: The estimated reductions in SO_2 (measured in pounds) emissions under real time electricity pricing in New York City across hour, fuel spread quartile and season. Estimates are generated by multiplying marginal emissions in an hour and fuel-price spread quartile by demand reduction in the same hour and spread quartile. Average hourly SO_2 emissions across the full sample are 769 pounds.

Table 4: Estimated NO_X Emissions Reductions Under Real Time Pricing

	No Summer				Summer			
	Spread Quartile							
Hour	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
6	-560	-199	-229	-214	-814	-230	-229	-253
7	-635	-211	-229	-231	-863	-281	-252	-278
8	-717	-239	-246	-256	-887	-309	-294	-332
9	-798	-272	-281	-292	-948	-431	-344	-397
10	-834	-288	-304	-314	-968	-415	-375	-434
11	-855	-302	-315	-320	-988	-435	-394	-472
12	-851	-304	-318	-327	-984	-441	-407	-479
13	-833	-304	-329	-334	-970	-490	-413	-488
14	-819	-297	-326	-328	-972	-482	-417	-500
15	-823	-289	-335	-323	-971	-482	-425	-516
16	-871	-301	-360	-347	-1019	-503	-453	-552
17	-979	-323	-372	-357	-1128	-494	-471	-580
18	-997	-331	-367	-343	-1079	-466	-454	-536
19	-973	-339	-375	-342	-1009	-430	-435	-493
20	-896	-310	-327	-315	-947	-432	-391	-455
21	-784	-247	-262	-251	-876	-343	-333	-381

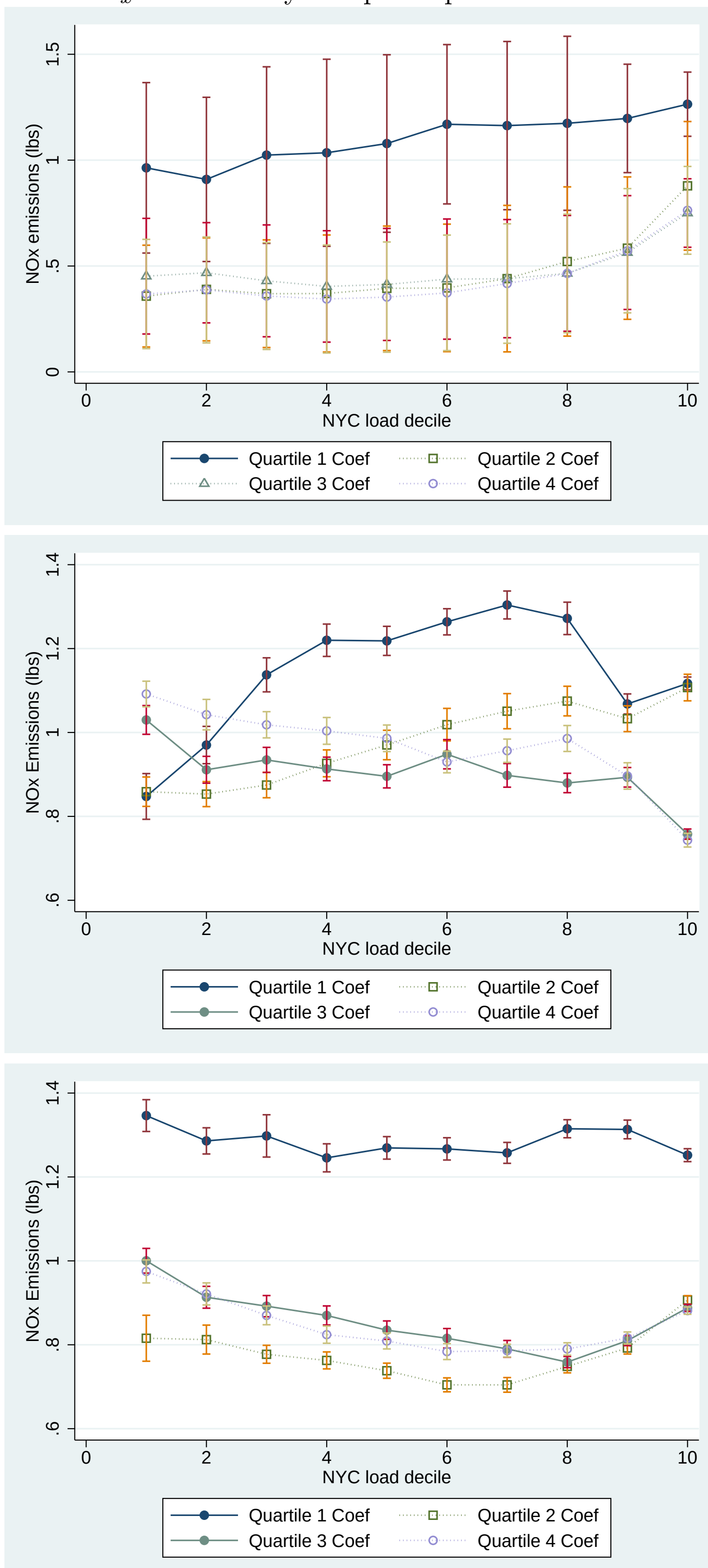
Note: The estimated reductions in CO_2 (measured in pounds) emissions under real time electricity pricing in New York City across hour, fuel spread quartile and season. Estimates are generated by multiplying marginal emissions in an hour and fuel-price spread quartile by demand reduction in the same hour and spread quartile. Average hourly NO_X emissions across the full sample are 1425 pounds.

Figure 3: CO_2 emissions by fuel price spread and NYC load level



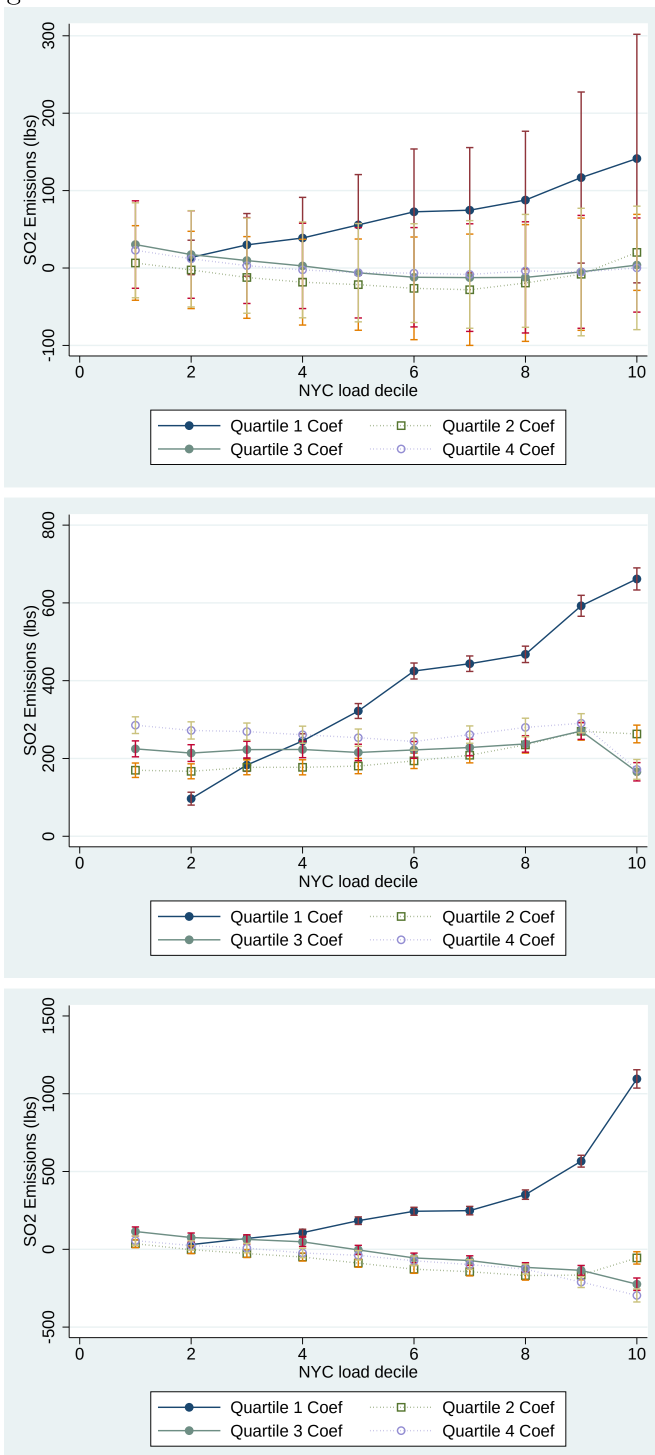
Note: The results of regressions estimating the marginal CO_2 emissions from a one megawatt increase in generation conditional on weather, month, and year fixed effects for all NYC generators (top panel) Astoria Generating Station (middle panel) and Ravenswood Generating Station (bottom panel) The vertical axis is the level of generation measured in megawatts. The vertical bars represent the 95% confidence interval for the coefficient estimate. All regressions include robust standard errors and in regressions for all generators in NYC standard errors are clustered at the facility level. This corrects for both intra-power plant correlation across time and possible serial correlation in the error term.

Figure 4: NO_x emissions by fuel price spread and NYC load level



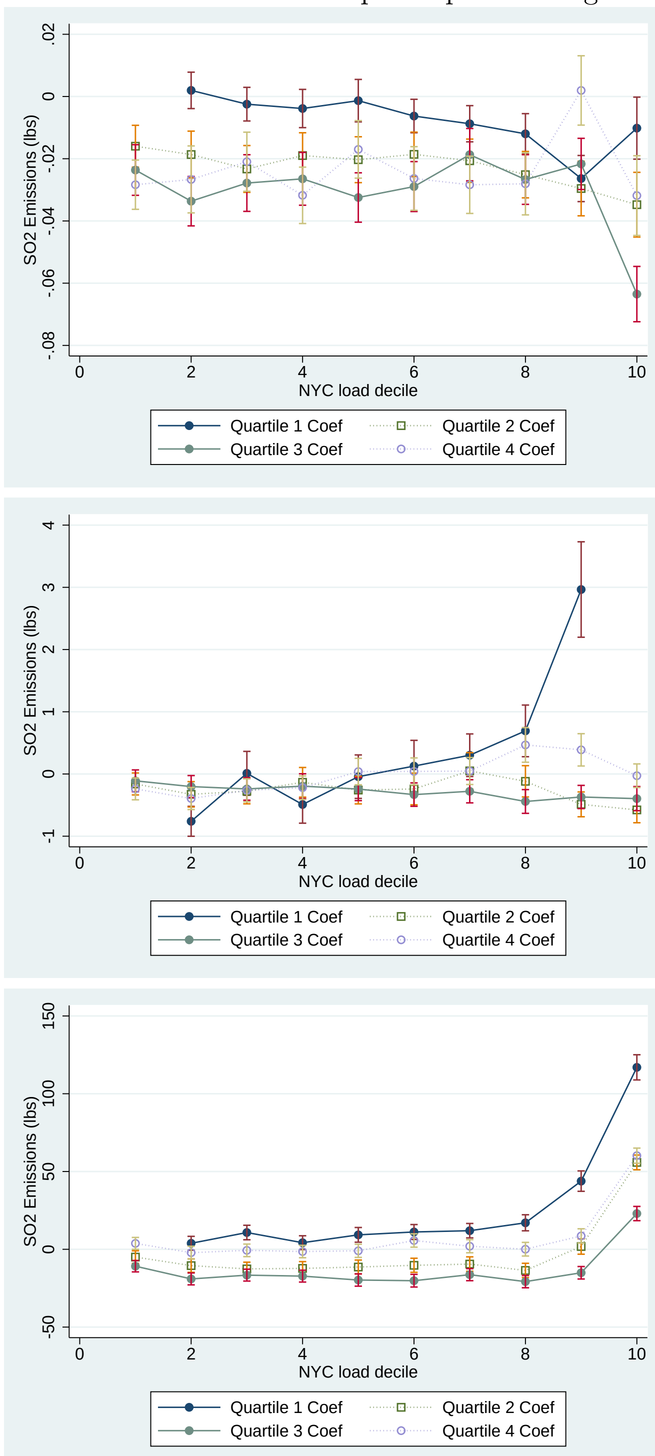
Note: The results of regressions estimating the marginal NO_x emissions from a one megawatt increase in generation conditional on weather, month, and year fixed effects for all NYC generators (top panel) Astoria Generating Station (middle panel) and Ravenswood Generating Station (bottom panel) The vertical axis is the level of generation measured in megawatts. The vertical bars represent the 95% confidence interval for the coefficient estimate. All regressions include robust standard errors and in regressions for all generators in NYC standard errors are clustered at the facility level. This corrects for both intra-power plant correlation across time and possible serial correlation in the error term.

Figure 5: Emissions estimates for intra month variation



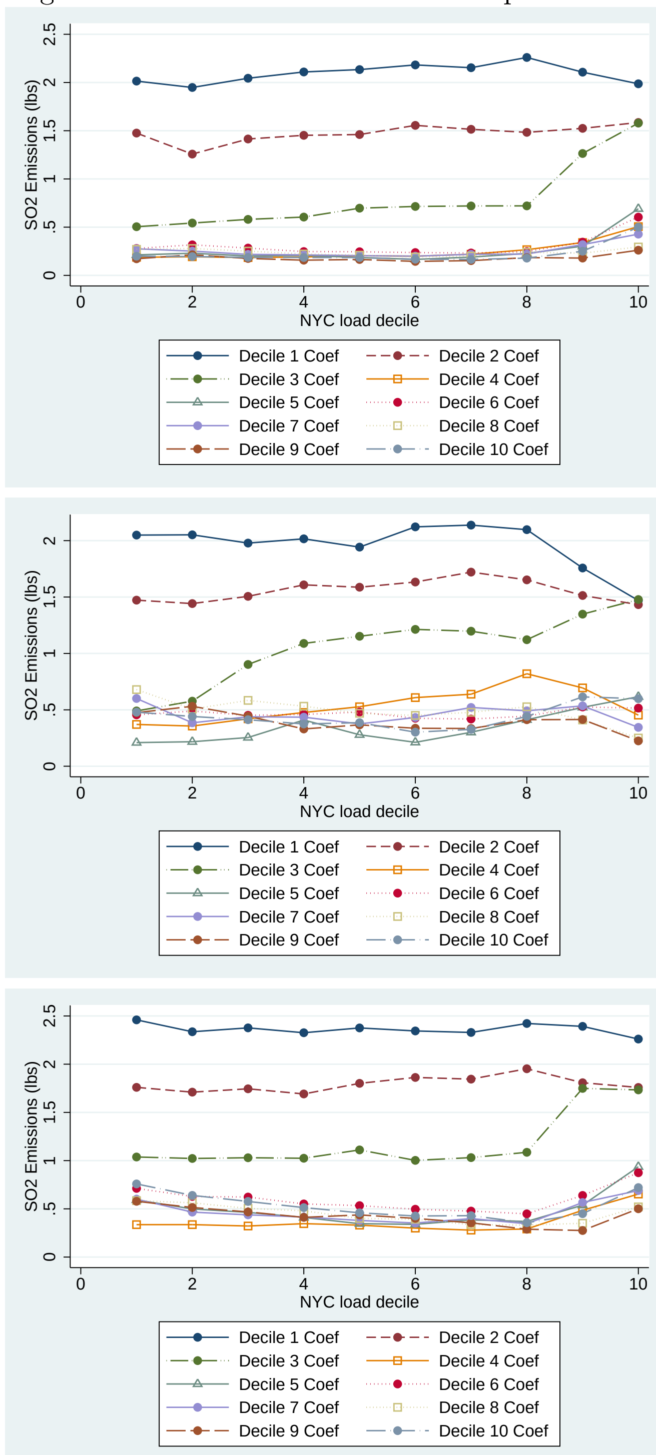
Note: The results of regressions estimating the marginal SO_2 emissions from a one megawatt increase in generation conditional on weather, month-by-year fixed effects for all NYC generators (top panel) Astoria Generating Station (middle panel) and Ravenswood Generating Station (bottom panel) The vertical axis is the level of $S0_2$ measured in pounds. The vertical bars represent the 95% confidence interval for the coefficient estimate. All regressions include robust standard errors and in regressions for all generators in NYC standard errors are clustered at the facility level. This corrects for both intra-power plant correlation across time and possible serial correlation in the error term. The average hourly SO_2 emissions level across the entire data set is 87.2 pounds.

Figure 6: Emissions estimates for power plants using other fuels



Note: The results of regressions estimating the marginal SO_2 emissions from a one megawatt increase in generation conditional on weather, month, and year fixed effects for all NYC generators Aurthur Kill (top panel) Astoria Energy (middle panel) and East River (bottom panel) The vertical axis is the level of emissions measured in megawatts. The vertical bars represent the 95% confidence interval for the coefficient estimate. All regressions include robust standard errors. This corrects for possible serial correlation in the error term.

Figure 7: Emissions estimates for fuel price deciles



Note: The results of regressions estimating the marginal SO_2 emissions from a one megawatt increase in generation conditional on weather, month, and year fixed effects using fuel price spread deciles, rather than quartiles. The figure represent all NYC generators (top panel) Astoria Generating Station (middle panel) and Ravenswood (bottom panel) The vertical axis is the level of generation measured in megawatts. All regressions include robust standard errors and in regressions for all generators in NYC standard errors are clustered at the facility level. This corrects for both intra-power plant correlation across time and possible serial correlation in the error term.