Consumer Cost Effectiveness of CO₂ Mitigation Policies in Restructured Electricity Markets

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Supporting Data
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SUPPORTING DATA

Analysis of 18 GW of Coal Missing in PJM

In the analysis above, we assumed that demand and the mix of generators in each region would stay the same as it was in 2012. Pending environmental legislation may force coal generators to retro-fit, and PJM estimates that 11 GW of coal are at “high risk” of retirement and another 14 GW are “at some risk” [26]. PJM estimates that the best physical screening for plants at risk of retirement are those over 40 years old and with capacity less than 400 MW [26]. We applied this screening tool to our mix of generators and removed 18 GW of old, small coal plants from the dispatch stack. Below in Figure S1, we show results with these coal plants removed.

Figure S1: Cost effectiveness of carbon mitigation policy options in PJM using 2012 data with 18GW of coal removed as the baseline. The graph on the left shows the marginal abatement costs of policies if transfer payments are neutral. The marginal cost of abatement is equal to the carbon price. The figure on the right shows the marginal abatement costs of policies from the consumer perspective.

Figure S1 above shows similar results to Figure 3 of the main text. This shows that the coal generators expected to be lost have high heat rates and are not be major contributors to our results in energy markets.

Effect of Wind on Market Clearing Prices in PJM

In Figure 2 in the main text above, we show how a carbon price increases market clearing prices. Below in Figure S2, we show how renewables lower market clearing prices.
Average Cost Effectiveness in MISO

We performed the same cost effectiveness analysis for MISO as we did for PJM and ERCOT. Hourly load data was unavailable for MISO, so the MISO hourly load was estimated by scaling down PJM data based on 2012 peak load differences [42] [43]. Hourly wind production was scaled from National Renewable Energy Lab’s eastern wind dataset [44] to meet annual generation levels reported for each region for 2012 [45] [46].

We found that the results were not as applicable for this research because the lack of fuel diversity leads to smaller wealth transfer effects than in the other regions (Figure S3). Of the three regions examined, MISO has the least fuel diversity and the dominance of coal means that market clearing prices rise quickly with carbon prices. MISO is the only region for which the model shows that new capacity is profitable with a carbon price without reaching a 20% reduction in carbon emissions. Below in Figure S3, we show Figure 1 from the main text with MISO included.
**Figure S3**: Carbon mitigation due to fuel switching as a result of a carbon price. Solid lines are for natural gas at $4/MMBTU; dashed lines are for $7 gas. The lines stop when new capacity is profitable as a result of a carbon price and natural gas price. In the $4 gas case, new NGCC plants are induced. In the $7 gas case, new wind plants are induced. We assume that the levelized cost of wind is $85/MWh and the levelized capital cost of a new NGCC plant is $135/MW-year [27]. NGCC plants may be profitable at slightly lower carbon prices than indicated in the figure because of revenue from capacity markets.

Below in Figure S4, we show the cost effectiveness of a 10% reduction in carbon emissions in MISO. Figure S4 shows that consumers would pay approximately ~$50/tCO₂ if either a carbon price or an RPS was used in the $7/MMBTU gas scenario. If gas was $4/MMBTU, a carbon price would be the more cost effective option for consumers.
Figure S4: Cost effectiveness of mitigating carbon 10% in MISO. We varied the cost of wind between $80-$120/MWh and the cost of gas from $4-$7/MMBTU. Colored boxed indicate the consumer point of view and gray boxes indicate the social point of view where wealth transfers are neutral.

Like other regions, an RPS is more cost effective for consumers when gas is expensive. However, because of the small differences in cost effectiveness, policy decisions are more likely to be driven by other factors.
Average Cost Effectiveness in PJM

Below in Figure S5, we show the average cost effectiveness of a 20% reduction in carbon emissions in PJM.

Figure S5: Cost effectiveness of mitigating carbon 20% in PJM. We varied the cost of wind between $80-$120/MWh and the cost of gas from $4-$7/MMBTU. Colored boxed indicate the consumer point of view and gray boxes indicate the social point of view where wealth transfers are neutral.
Average Cost Effectiveness in ERCOT

Below in Figure S6, we show the average cost effectiveness of a 20% reduction in carbon emissions in ERCOT.

**Figure S6:** Cost effectiveness of mitigating carbon 20% in ERCOT. We varied the cost of wind between $80-$120/MWh and the cost of gas from $4-$7/MMBTU. Colored boxed indicate the consumer point of view and gray boxes indicate the social point of view where wealth transfers are neutral.
Average Cost Effectiveness for 10% Reduction in CO₂ Emissions

We summarize our results for PJM, ERCOT, and MISO for a 10% reduction in carbon dioxide emissions from the baseline year of 2012 in Table S1.

Table S1: Cumulative Cost of Carbon Abatement for 20% Reduction of CO₂ in PJM and ERCOT [$/tCO₂]

| CO₂ Reduced | Region | Perspective | Carbon Price | RPS  | Carbon Price | RPS  | Carbon Price | RPS  |
|-------------|--------|--------------|--------------|------|--------------|------|--------------|------|
|             |        |              | $4 Gas       | $7 Gas | $4 Gas  | $7 Gas | $4 Gas  | $4 Gas |
| 10%         | PJM    | Social       | 5            | 30    | 90          | 80  |          |       |
|             |        | Consumer     | 40           | 220   | 80          | 50  | 65        | 85   | -20    | 90   |
| 10%         | ERCOT  | Social       | 5            | 40    | 120         | 100 |          |       |
|             |        | Consumer     | -20          | -60   | 100         | 30  |          |       |
| 10%         | MISO   | Social       | 10           | 30    | 90          | 75  |          |       |
|             |        | Consumer     | 30           | 50    | 70          | 50  |          |       |
Results if Renewable Output is Baseload

In the analysis above, we assumed that wind fills the entire renewable energy portfolio. For completeness, we ran the analysis for PJM assuming that the output of the renewable portfolio was baseload. The results are shown in Figure S7 below.

![Figure S7](image-url)

**Figure S7**: Cost effectiveness of carbon mitigation policy options in PJM using 2012 data assuming the renewable energy output is constant. The graph on the left shows the marginal abatement costs of policies if transfer payments are neutral. The marginal cost of abatement is equal to the carbon price. The figure on the right shows the marginal abatement costs of policies from the consumer perspective.