Carbon Policy and the Emissions Implications of Electric Vehicles

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Motivation: Overlapping and interacting policies

Overlapping and interacting policies can create unintended consequences

- Price policies are considered additive
- And overlapping quantity policies can be substitutes
  - e.g., Goulder et al. (2012), Perino et al. (2019)
- It gets more complicated when you mix them
  - e.g., Fischer et al. (2013)

Motivation: Electric vehicles (EVs)

- Decarbonizing transport is challenging
- Extensive policy support for EVs:
  - Fuel economy standards with generous EV credits
  - Tax credits
  - Gasoline/diesel car bans
- EVs are only 5% of global sales in 2020, but projections have them rising fast
- $200 billion in EV R&D over next 5 years (AlixPartners)


BUSINESS

California's Ban on New Gas Cars Further Upends Auto Industry

Tougher emission rules threaten internal combustion engine; investors flock to Tesla, electric-vehicle startups

GM’s announcement (Jaguar and Volvo just followed)

G.M. Will Sell Only Zero-Emission Vehicles by 2035

The move, one of the most ambitious in the auto industry, is a piece of a broader plan by the company to become carbon neutral by 2040.

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General Motors plans an electric Hummer pickup, with a high-end version due in showrooms this fall.

This study asks

Is there an interaction between carbon and EV policy?

- Does a carbon price influence the emission reductions from more EVs?
  - A cleaner electric grid might mean that EVs lead to greater emission reductions
  - But what matters is the generation *on the margin*
  - A carbon price may influence what is on the margin

Related literature

- Work on overlapping and interacting policies
  - Gerarden et al. (2020), Goulder et al. (2012), Fischer et al. (2013), Bohringer & Rosendahl (2010), etc.
- Growing work on electric vehicles
  - Rapson and Muehlegger (2020), Holland et al. (2016), Graff-Zivin et al. (2014), Li (2020), Springel (2020), Zhou & Li (2018), Li et al. (2017), Xing et al. (2020), etc.

This paper

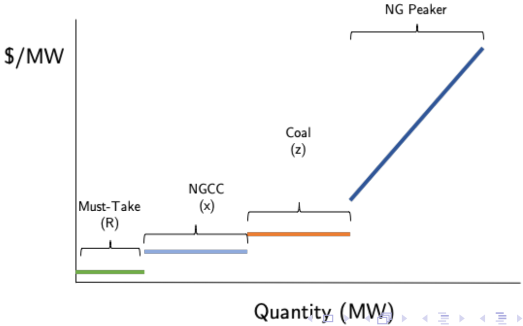
- Explores complementarity between carbon policy and high EV penetration
  - Use **theory** to show the conditions for when a carbon price could lessen the emission reductions from EVs
  - **Empirically** demonstrate this effect using recent data
  - Use a detailed dynamic **simulation** of the electricity and transportation sectors to show effects to 2050
- Our findings show that a moderate carbon price could reduce the emission reductions from EVs in many regions

Outline

Outline

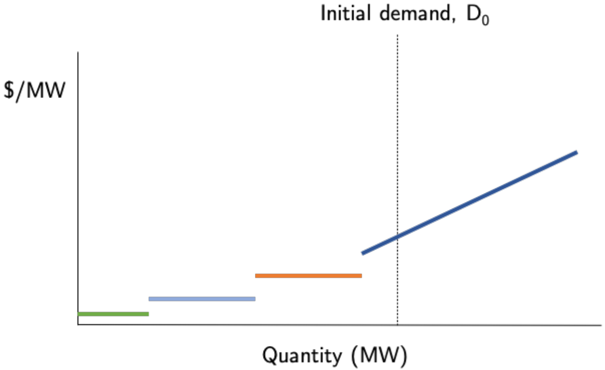
Static illustrative model of electricity supply

- 4 plant types (must-take, combined cycle, coal, and natural gas peakers) in a competitive market, where each plant type j has a CO_2 emissions factor β_j
- Must-take, NGCC, and coal have flat marginal cost curves
- Natural gas peakers have increasing marginal cost



Electricity demand

- Initial inelastic demand, D_0



Effect of a carbon price

- Carbon price τ increases marginal cost for plant *j* by $\beta_j \tau$
  - The magnitude of τ determines the extent of the reordering

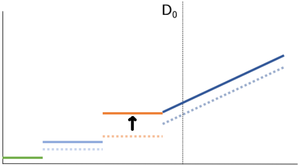


Figure: Low Price

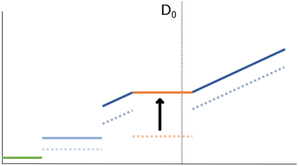


Figure: Mid Price

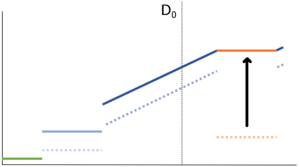
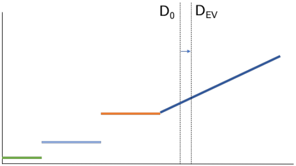


Figure: High Price

Effect of electric vehicles added

- EVs added to the grid by an additional policy will use kWh by the marginal generator



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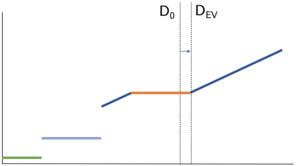

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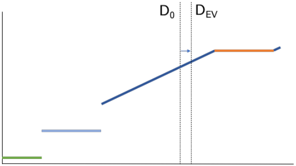


Figure: High Price

Outline

Empirical exercise

- Goal: Explore if this effect exists in the data
- But nearly no carbon pricing in much of the United States
- Our basic strategy: use changes in the ratio of the natural gas to coal costs
  - Analogous strategy to Cullen & Mansur (2017)
  - Idea is that a carbon price will increase the marginal costs of coal plants relative to gas plants
  - So we exploit variation in the ratio of coal to gas prices

Data

- Hourly load and hourly net generation by source
  - From four ISOs: ERCOT, MISO, PJM, SPP
- Plant-level monthly data on coal and gas fuel expenditures, generation, fuel consumption (EIA Form 923)
  - Allows us to calculate the variable fuel cost per MWh for every month
  - We match plants to regions and calculate generation-weighted monthly gas and coal prices
- Data cover Jan 2014-Dec 2019

Map of Electricity regions

Variation in the coal-to-gas price ratio

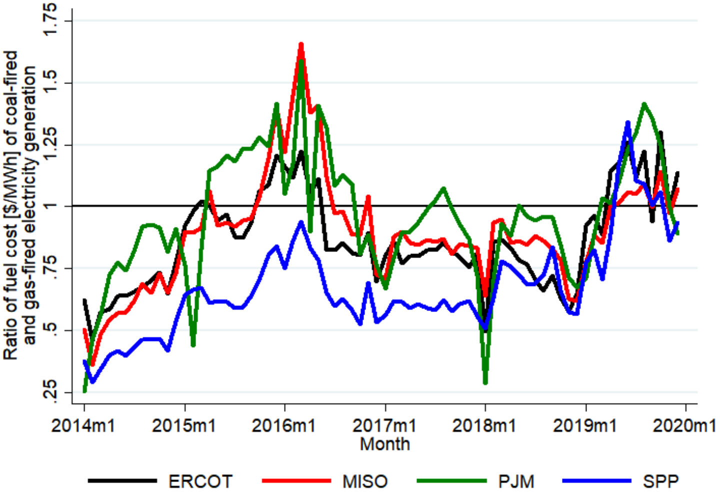


Figure: Ratio of the variable fuel cost of coal-fired to gas-fired electricity generation by month.

Variation put in terms of carbon prices

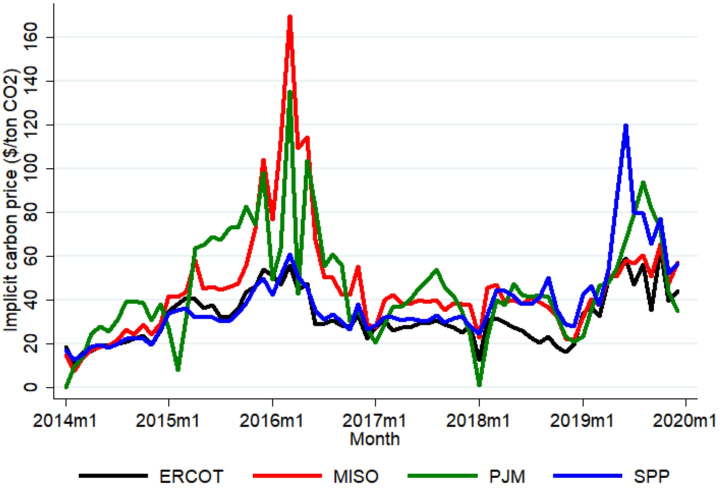


Figure: Implicit carbon price (normalized to PJM in 2014m1) corresponding to the coal-gas price ratio.

Empirical specification

Similar to Holland et al. (2016), the generation from coal and gas for each region is given by:

$$q_{ft} = \sum_{p \in \{\text{peak,offpeak}\}} \beta_p 1(peak)_p load_t + \gamma_S q_{\text{solar},t} + \gamma_W q_{\text{wind},t} + \delta_{tmy} + \epsilon_{ft}$$

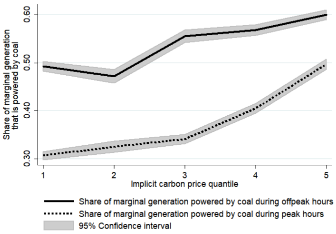
where

- q_{ft} is hourly output for fuel f in hour t
- $1(peak)_p$ is a dummy for 7am-10pm
- $load_t$ is electricity demand in the region
- δ_{hmy} are hour-of-the-day $\times$ month-of-sample fixed effects

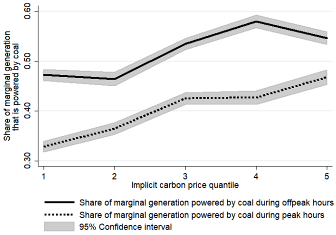
Empirics

- We run our specification separately for ranges of implicit carbon price ratios
  - These are based on splitting the sample into roughly equal parts for each region based on the ratio
  - Quantiles at: $8, $27, $35, $40, $50, and $120/ton
- Idea is to see how different carbon prices would change the dispatch decision
  - Focus is on coal and where coal is in the merit order
  - Remaining share is almost entirely natural gas
  - Renewables and nuclear are almost always inframarginal

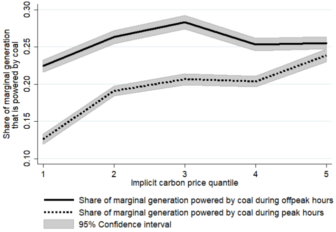
Marginal generation from coal rises with CO_2 price



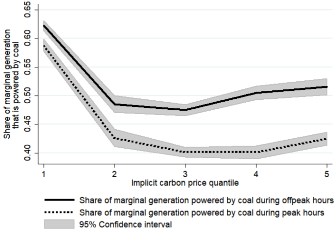
(a) MISO



(b) SPP

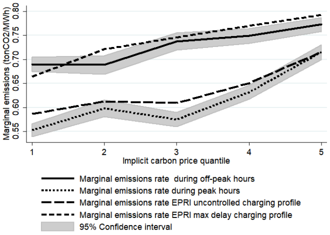


(c) ERCOT

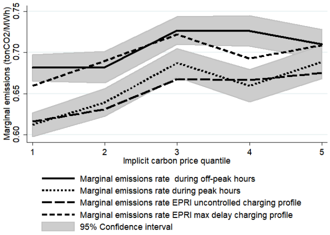


(d) PJM

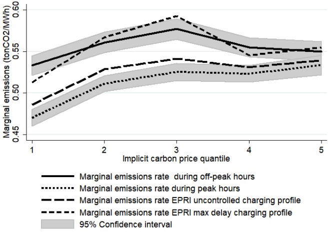
CO_2 emission rate on the margin rises with CO_2 price



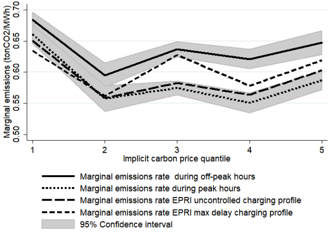
(a) MISO



(b) SPP



(c) ERCOT



(d) PJM

Outline

Why a dynamic simulation?

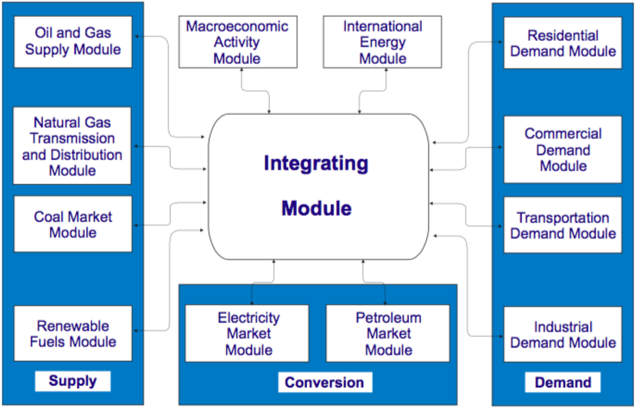
- Results so far tell us about the marginal emissions in the short run based on changes in dispatch
- But what about the long run?
  - Demand will not be perfectly inelastic
  - The increase in electricity demand from EVs may be inframarginal
  - Retirements of old plants
  - Builds of new plants
  - Renewables will be getting cheaper

Our approach

The National Energy Modeling System (“Yale-NEMS”)

- Developed by the Energy Information Administration
- Used to produce the Annual Energy Outlooks (AEO) and many analyses
  - Brown et al. (2001), Auffhammer & Sanstad (2011), Brown et al. (2011), Bordoff & Houser (2014), Gillingham & Huang (2019), Small (2013), Gallagher & Collantes (2008)
- 13 modules covering all major sectors and macroeconomic feedbacks
- Model runs through 2050
- Regional disaggregation varies by module

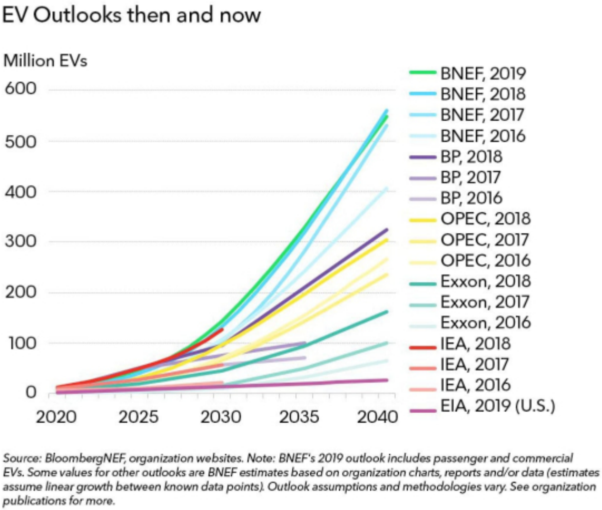
Schematic of Yale-NEMS



Primary scenarios

- Reference case (similar to AEO)
- High EV demand (based on Bloomberg New Energy Finance)
- Carbon pricing (starting at $2/ton and rising to $30/ton by 2040)
- High EV demand + carbon pricing policies

BNEF global scenario



Our modeled EV penetration

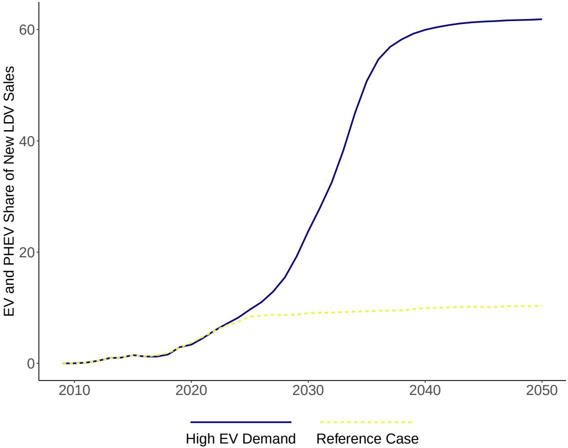


Figure: Share of new car sales that are EVs or PHEVs in the high EV demand case compared to the reference case.

EVs powered by coal under moderate carbon price?

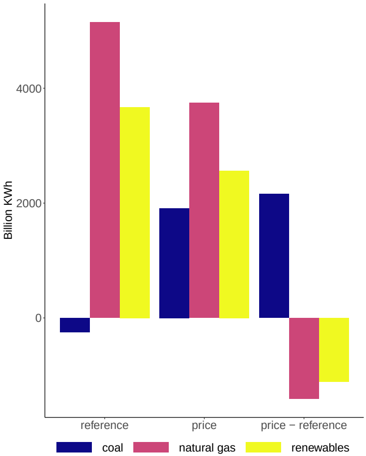


Figure: Additional generation associated with extra EVs, with and without a carbon price (sum over 2020-2050). The rightmost bars are the difference between the effects with and without a carbon price.

Coal generation increases due to EV demand

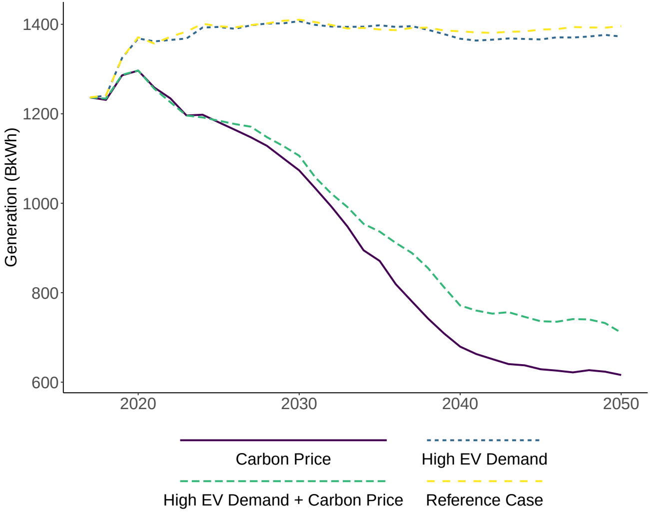


Figure: Total generation from coal.

Most of effect is from delayed coal plant retirements

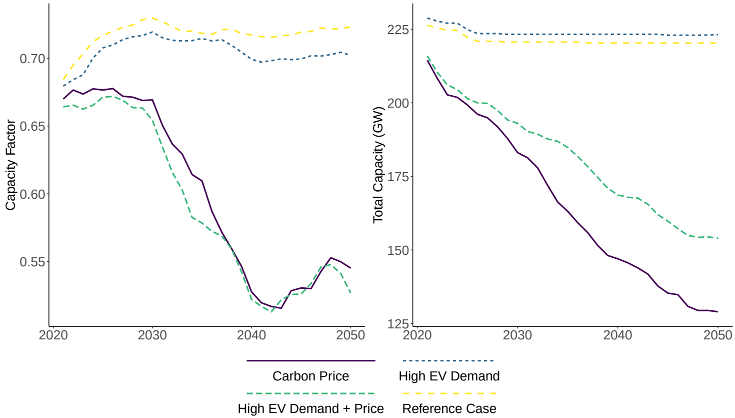
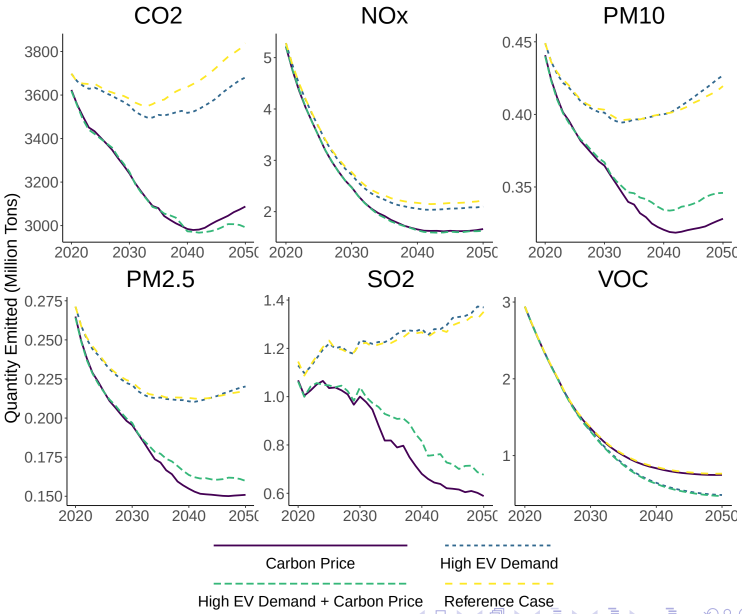


Figure: Coal capacity factor and total capacity.

Combined emissions



Discounted avoided damages

- We calculate the discounted sum of avoided pollution damages in each scenario relative to the reference case
- The combination of high EV demand and a carbon price can result in lower benefits than carbon pricing alone

Table: Discounted Avoided Pollution Damages to 2050

	(1)	(2)	(3)	(4)
	Carbon price in 2040			
	\$5.30/ton	\$30/ton	\$50/ton	\$70/ton
Electric Vehicles	2.70	2.70	2.70	2.70
Carbon Price	2.62	21.08	33.03	41.61
Electric Vehicles + Carbon Price	5.11	20.90	34.25	43.00
Benefit Adding EVs to Carbon Price	2.49	-0.18	1.22	1.39
Net Complementarity	-0.21	-2.88	-1.48	-1.31

Notes: Units are billions of 2016 \$/year and all values are changes relative to the reference case. The discount rate is 3%.

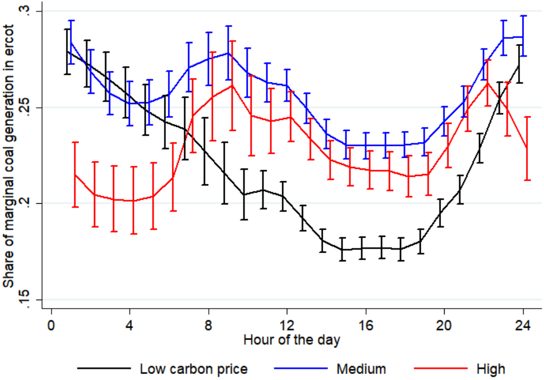
Outline

Conclusions

- A cautionary tale about interacting policies
  - A dispatch + retirement effect can lead to a substitutability between carbon and EV policies
  - The welfare benefits of EV policies can be lower under a range of carbon prices
  - In historical data and a prospective dynamic simulation
- Some important context though:
  - Most likely in regions with lots of inframarginal coal generation
  - With a high-enough carbon price, coal is retired
  - The carbon price reduces emissions in all cases
- Similar interaction effects are likely in other sectors

Thank you!

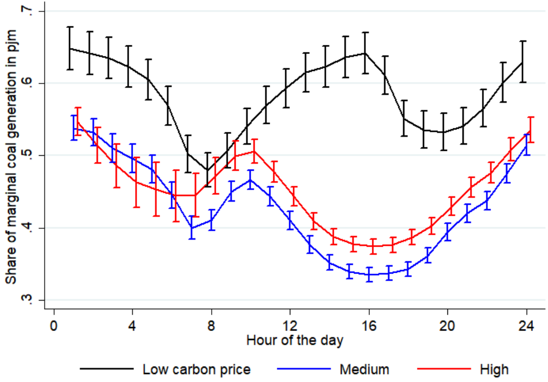
Appendix: Coal is pushed to and beyond the margin in ERCOT



(a) ERCOT

Figure: Marginal generation that is coal-fired generation in ERCOT.

Appendix: Coal is pushed beyond the margin in PJM



(a) PJM

Figure: Marginal generation that is coal-fired generation in PJM.

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