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Strategic Policy Choice in State-Level Regulation: The EPA's Clean Power Plan[†]

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The EPA's Clean Power Plan sets goals for CO_2 emissions rate reductions by 2030 that vary substantially across states. States can choose the regulatory mechanism they use and whether or not to join with other states in implementing their goals. We analyze incentives to adopt rate standards versus cap-and-trade with theory and simulation. We show conditions where adoption of inefficient rate standards is a dominant strategy from both consumers' and generators' perspectives. Numerical simulations of the western electricity system highlight incentives for uncoordinated policies that lower welfare and increase emissions relative to coordination. (*JEL* H76, Q53, Q54, Q58)

Within the United States, state-by-state variation in regulatory approaches has been more of the norm than an exception. For example, within the utility industries, individual state regulatory commissions have used substantially different variations on the rate-of-return regulatory framework, while some states have chosen to rely on wholesale power markets instead of vertically integrated utilities. In the environmental realm, the US Environmental Protection Agency (EPA) has often deferred to state or local air quality regulators to develop specific implementation plans to achieve the EPA's environmental mandates. The Clean Air Act, one of the dominant environmental regulatory instruments, requires the EPA leave regulatory decisions up to individual states.

In electricity markets, the regulatory actions of states, or even local communities, often affect the market outcomes in surrounding areas because electricity flows throughout regional networks. In the climate change policy arena, California and states in the northeastern US have faced this issue with their unilateral adoption of cap-and-trade programs limiting carbon emissions from in-state sources. In both

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instances, there have been concerns that such actions could spur "leakage" of both emissions and of beneficial economic activity to the neighboring uncapped regions; specifically, while emissions may decrease within the regulatory jurisdictions, emissions may *increase* elsewhere as output increases from unregulated power plants.[1]

A more subtle form of economic spillovers can arise when individual states respond to regulatory requirements with different instruments. The choice of instrument affects each power plant's opportunity cost of selling electricity. Therefore, certain policies may provide a competitive advantage to power plants within a particular state, and this advantage will depend on the policies adopted in other states. In the face of these incentives, it is not clear the equilibrium outcome will yield an efficient mix of policies.

Recent actions by the EPA to address greenhouse gas emissions create a similar dynamic. In this case however, the stakes are much higher than the examples above. The EPA's Clean Power Plan (CPP) proposes major reductions in carbon emissions from electricity generators in the United States. Focusing on the electricity sector, the CPP uses existing provisions of the Clean Air Act to regulate a substantial share of carbon emissions. Due in part to inaction at the federal level, recent US climate policy has been driven almost exclusively by state and regional initiatives. This has raised concerns over inefficiencies from uncoordinated policies (Bushnell, Peterman, and Wolfram 2008). A national framework holds the potential to decrease inefficiencies created by the patchwork of state and regional policies and could improve US standing in international climate negotiations (Newell, Pizer, and Raimi 2012; Stavins 2008).

We analyze the potential effects of the CPP in terms of electricity market outcomes and state adoption incentives using both theory and numerical simulation. The CPP establishes state-level targets for carbon emissions rates in lbs of carbon dioxide per megawatt hour of electricity generated (lbs per MWh). States can adopt the default rate standard or can instead adopt a "mass-based" regulation, i.e., a cap-and-trade (CAT) system. Further, states can form coalitions by adopting either a CAT regulation or rate standard, or by trading "emission rate credits" across states. The effects on consumers and producers within a state depend on both the type of regulation adopted by each state and regulations adopted by its electricity trading partners. Furthermore, the states' private incentives may be at odds with those of a national social planner.

We have five main results. First, we show industry supply, i.e., the merit order, can be efficient under a CAT regulation, rate standard, or mixed regulation. However, supply efficiency requires stringent conditions for rate standards or for mixed regulation. Moreover, supply efficiency is necessary but not sufficient for efficiency. Echoing earlier results in the literature, e.g., Helfand (1991); and Holland, Hughes, and Knittel (2009), we show that in general only CAT can be efficient.

Second, we illustrate important differences in the incentives of a unified coalition of states versus the incentives of a single state or of various stakeholders. For the coalition of states, adoption of CAT is best from an efficiency perspective. However,

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[1] See Fowlie (2009) and Chen (2009).

for an individual state or for stakeholders the incentives are more nuanced and may result in an inefficient policy as a dominant strategy.

Third, we explore our theoretical predictions using a simulation model of the western interconnection of the US electricity grid. Relative to business as usual, we find that a West-wide CAT implementing the Clean Power Plan: increases social welfare by approximately \$2 billion; decreases carbon emissions by 71 million metric tons (MMT), about 21 percent; and has reasonable marginal abatement costs of \$21 per metric ton (MT).[2] Failure to coordinate policies results in a merit order which can be "scrambled" quite dramatically and in substantial deadweight loss. State-by-state CAT standards reduce social welfare by approximately \$200 million relative to a West-wide CAT. The inefficiency is even worse under state-by-state rate standards. Mixed regulation creates the possibility of additional scrambling of the merit order as well as of emissions leakage, thereby introducing additional inefficiencies.

Fourth, we simulate the incentives of stakeholders and show that various stakeholders have an incentive to deviate from a coordinated policy regime. From a private surplus perspective, the coastal states would have an incentive to deviate from a West-wide CAT, and the inland states would have an incentive to deviate from a West-wide rate standard. Overall, these strategic interactions tend to result in uncoordinated policies across the regions.

Finally, we analyze how the design of CAT regulations affects entry incentives under the CPP. New generation may or may not be included in emissions caps for states that adopt CAT regulations. This creates the potential for emissions leakage via investment in new fossil fuel generation outside of the cap.

This work contributes to several literatures. Our findings echo concerns about environmental and economic spillovers from local climate policies. First, environmental targets can be undermined if production is able to shift away from the jurisdictional reach of the regulator through either leakage or reshuffling of production sources.[3] Second, local regulatory programs are unlikely to lead to the efficient allocation of abatement across regions as marginal abatement costs are not equal. Third, regulatory action in one area may put firms in that region at a competitive disadvantage relative to firms in unregulated regions. These concerns have been a challenge for regional climate initiatives in the US. More generally, concerns over leakage have been a challenge for international climate agreements. In crafting the European CO_2 market, as well as the now defunct Waxman-Markey bill that would have established a national cap in the United States, much attention was paid to the "competitiveness" question, which is fundamentally related to how vulnerable domestic producers are to leakage from imports.

Our theoretical model is most closely related to Fischer (2003). Fischer analyzes carbon trading between CAT and rate standards and finds trading raises emissions. We extend this work by analyzing two components necessary for understanding the CPP. First, we explicitly model trading in the product market, electricity, that

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[2] The EPA's analysis indicated average abatement costs from \$4 to \$36 per ton of carbon. (See tables ES-2, ES-3, and ES-5 of Office of Air and Radiation, and Office of Air Quality and Planning Standards 2015.)

[3] See Bushnell, Peterman, and Wolfram (2008); Fowlie (2009); and Chen (2009).

crucially affects the interactions of the states' policy choices. Second, we analyze states' adoption incentives for CAT and rate standards. Burtraw et al. (2015) also simulate electricity system outcomes under the CPP. They show the choice of allocation policy can mitigate some of the perverse effects of inconsistent state regulatory choices. However, as we show here, states may not find it in their interest to mitigate those effects. Finally, our work also contributes to the literature on rate-based environmental regulation.[4]

Section I discusses the Clean Power Plan in more detail and provides policy background. Section II develops the theoretical model and derives the theoretical results. Section III presents the simulation model and Section IV describes the results. Section V concludes.

I. The Clean Power Plan: Greenhouse Gas Regulation under the Clean Air Act

Since the landmark 2007 decision by the US Supreme Court in *Massachusetts v. EPA*, the EPA has taken several steps to limit GHG emissions under the Clean Air Act (CAA). A significant milestone occurred on August 3, 2015 when the Obama administration released the Clean Power Plan (CPP) regulating GHG emissions from existing power plants. Rather than following the usual permitting process, the CPP instead uses provisions in Section 111 of the CAA. Section 111 provides a flexible framework for regulation, but also imposes constraints on the types of policies that may be implemented under the CPP. Regulation under Section 111 requires that the EPA establish "standards of performance" which are defined as "a standard for emissions of air pollutants which reflects the degree of emission limitation achievable through the application of the best system of emission reduction." The text also requires state-level implementation of the standards.

To estimate the best system of emissions reduction, the Clean Power Plan uses three "building blocks."[5] The first building block focuses on emissions reduction from fossil steam generation through heat rate (efficiency) improvements. The second building block focuses on shifting generation from relatively dirty coal-fired plants to relatively cleaner gas-fired plants. The third building block requires increased generation from low emissions or zero-emissions generation (e.g., renewables). Based on these building blocks, the EPA allows states to choose between rate standards, CAT regulation, and "state measures."[6]

Rate standards can be based on national or state-blended rates. National rates (in lbs CO_2 per MWh) for existing fossil steam and natural gas combined cycle generation are based on the best system of emissions reduction.[7] The EPA calculates rates separately for the eastern and western electricity interconnections as well as for the

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[4] See also Huang et al. (2013), Pizer (2005), and Zilberman et al. (2013).

[5] The initial CPP proposal included a fourth building block for energy efficiency. While energy efficiency measures are not used to calculate the rate standards in the final rule, covered generators can still use energy efficiency programs to generate emission rate credits and can use the credits to meet CPP targets.

[6] The CPP defines "rate-based standards" and "mass-based standards." We simply refer to "rate standards" and "CAT" throughout.

[7] Fossil steam includes coal, oil, and natural gas steam generation units. Covered units are those capable of selling at least 25 MW of electricity to a utility power distribution system. New generation is not covered under the rate standard.

Electric Reliability Council of Texas. The national rates for each technology are the highest of the three calculated regional rates, i.e., the most lenient. State-blended rates are calculated as the generation-weighted average of the national rates based on each state's 2012 generation (MWh) from fossil steam and natural gas combined cycle units. State-blended rates vary from a 0 percent reduction in the emissions rates for Connecticut, Idaho, and Vermont to more than a 38 percent reduction in the emissions rate for Montana. Figure E1 in the online Appendix shows the rate reductions states must achieve, on average, over the period from 2022 to 2029.

CAT standards can either include or exclude emissions from new generation. When new generation is excluded, CAT standards are calculated by multiplying the state's rate standard target by the sum of the state's 2012 generation and twice the EPA's projected growth in renewable generation. When emissions from new generation are included, the CPP specifies alternate CAT targets. These standards allow for extra emissions called "new source complements." This provides an incentive for states to include emissions from new generation under their caps. The average state-level increase from new source complements for western states is about 4 percent.

Finally, under a "state-measures" approach, states can implement alternate regulations, and not federal CPP rules, so long as the emissions reductions under the state rules are greater than the federal requirements. State measures could include existing market-based policies, such as California's cap-and-trade law or the Regional Greenhouse Gas Initiative in the Northeast. Alternatively, these rules could take the form of more prescriptive renewable energy or energy efficiency policies.

To provide additional compliance flexibility, the CPP creates tradeable "emission rate credits." A regulated generator earns emission rate credits when emissions reductions exceed the rate standard.[8] Emission rate credits are also earned from increased generation using zero carbon sources or through energy efficiency measures that reduce total load.

Based on one of the standards above, the individual states must adopt compliance plans, either alone or as part of a coalition of states. The CPP neither compels states to adopt a CAT nor compels states to follow a regional approach. This flexibility could allow states to tailor their regulations to better fit their unique circumstances. Alternatively, the flexibility could lead states to adopt inefficient regulations that benefit some stakeholders at the expense of others and lead to significant impacts in other states.

Our analysis below focuses on the two main compliance paths, rate standards and CAT regulation. While the state-measures approach does allow for alternate prescriptive policies, most states will likely adopt one of the market-based policies, which are the subject of our analysis. To the extent prescriptive policies change the implicit or explicit costs of clean and carbon-intensive generation, our analysis captures many of the forces at work in less market-oriented policies. Further, since prescriptive policies are likely less efficient than the market-based policies we study here, our results represent an upper bound on welfare gains under the CPP.

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[8] Using our notation, the number of emission rate credits (ERCs) generated is given by: $ERC_i = q_i \times \frac{\sigma_s - \beta_i}{\sigma_s}$.

II. The Model

Consider a model of electricity generation and consumption in multiple states (regions). Let s index the states. Since electricity cannot be economically stored, prices vary across time if demand varies. Let t index hours and assume electricity flows freely across the states so that the electricity price in hour t is p_t and is common across all the states.[9] Total demand at time t is given by $D_t(p_t)$ and (net) consumer surplus by CS.[10, 11]

Supply in the model comes from a variety of generating units each with a constant marginal cost of generation and a limited capacity. Since the generating units may be regulated differently across states, we differentiate generating units by their location. Let i index the technologies (e.g., coal-fired, combustion turbine, etc.) and s index the states. Assume c_i is the marginal cost of generating from technology i; $\bar{q}_{si}$ is the installed capacity in state s of technology i; and β_i is the carbon emissions rate of technology i.

Under a market-based carbon regulation, costs also include carbon costs. Let τ be the social cost of carbon, and let $r \in \{BAU, CAT, RS\}$ index the carbon regulations: "business as usual," "cap-and-trade," and "rate standards."

Define the *full marginal cost*, FMC_{si}^{r}, as the sum of the marginal generation cost plus generators' (private) carbon cost, i.e., the cost of any carbon permits.[12] Below we define the full marginal cost for CAT and rate standards. In the absence of carbon regulation, i.e., in BAU, private carbon costs are zero and $FMC_{si}^{BAU} = c_i$. We also define the *full marginal social cost* as the marginal generation plus social carbon costs, i.e., $c_i + \beta_i \tau$.[13] Welfare, W^r, under regulation r is defined as the gross consumer surplus less full social costs, or, equivalently, the sum of net consumer surplus, generator profit, and any carbon market revenue minus carbon damages.

The supply from each technology is determined by comparing the electricity price with the full marginal cost. Generators supply at capacity if the electricity price exceeds their full marginal cost, supply nothing if the price is below their full marginal cost, and supply any amount up to capacity if the price equals their full marginal cost.

The market supply is determined by aggregating the supply from each generation technology. The resulting market supply is a nondecreasing step function which orders the technologies by their full marginal cost. The order of the technologies along the supply curve determines the order in which generation units would be called into service as demand increases and is called the *merit order*.

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[9] In the simulations, we extend the model to include transmission constraints. Other transmission costs, such as system costs and losses, are assumed to not vary by regulatory scenario.

[10] CS is found by integrating under the demand curve and above the price and summing over t. To analyze the distribution of consumer surplus, CS_s, across the states, we assume that each state's share of demand is a constant fraction of total demand. We do not account for programmatic investments that would shift the demand curve.

[11] Our definition of consumer surplus is surplus in wholesale markets. Implicitly we assume that wholesale prices are (eventually) passed through to end consumers. Modeling the intricacies of regulated retail rates, e.g., increasing block rates, two-part tariffs, etc. is beyond the scope of this paper. (See Borenstein and Holland 2005 and Borenstein 2012).

[12] We use "private" carbon costs to denote the portion of generators' compliance costs from carbon permit purchases. This is to distinguish these costs from "social carbon costs," i.e., externalities from carbon emissions.

[13] The full marginal social cost does not depend on the state or the carbon regulation.

The equilibrium electricity price in hour t is found from the intersection of hour t demand and market supply. Specifically, under carbon regulation r, the price in hour t is given by

$$p_t^r = \min\left\{p \,:\, D_t(p) \leq \sum_s \sum_i \Phi(FMC_{si}^r \leq p)\,\bar{q}_{si}\right\}, \tag{1}$$

where Φ is an indicator function that takes the value one if the argument is true and zero otherwise. Thus $\Phi(FMC_{si}^r \leq p)$ is one if $FMC_{si}^r \leq p$, i.e., if technology i is willing to supply at price p and is zero otherwise. The set defined in equation (1) is the set of prices for which there is excess supply. The minimum of this set will either be a price at which demand exactly equals market supply when all inframarginal generators supply at capacity (i.e., on a vertical portion of the supply curve) or will be a price at which any smaller price would have excess demand (i.e., on a horizontal portion of the supply curve).

Based on these equilibrium prices, we can now characterize the equilibrium generation and profits of each technology. If q_{sit}^r is equilibrium generation in state s from technology i in hour t under regulation r, then profits are defined as

$$\pi_{si}^r \equiv \sum_t (p_t^r - FMC_{si}^r)\, q_{sit}^r, \tag{2}$$

for technology i in state s under carbon regulation r.[14] Finally, we define equilibrium carbon emissions as

$$Carbon^r = \sum_s \sum_i \sum_t \beta_i q_{sit}^r. \tag{3}$$

A. *Cap-and-Trade* (*CAT*) *Regulation*

We now turn to equilibrium under a cap-and-trade (CAT) regulation limiting total carbon emissions. Let E_s be allowable emissions in state s and p_{cs} be the price of tradeable certificates for one unit of carbon emissions in state s. It is well known that such a cap-and-trade program raises costs of generators in proportion to their carbon emissions, and thus the full marginal cost of technology i is $FMC_{si}^{CAT} = c_i + \beta_i p_{cs}$ in state s.

These full marginal costs are illustrated in panel A of Figure 1. The figure shows the marginal costs of four technologies: nuclear (c_N), coal (c_C), gas (c_G), and oil (c_O). As illustrated, the unregulated merit order would be first nuclear, then coal, then gas, and finally oil because $c_N < c_C < c_G < c_O$. If the emissions rates are such that $\beta_O > \beta_C > \beta_G > \beta_N = 0$, the carbon regulation increases the full marginal costs of coal-fired generation more than of gas-fired generation due to coal's higher carbon emissions. Thus as illustrated the CAT regulation switches the

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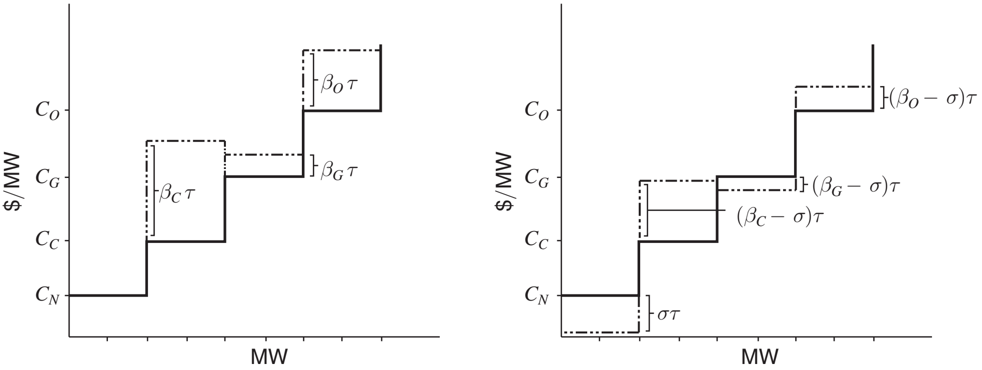
[14] The equilibrium supply has three cases. If price is above marginal cost, then generation is at capacity. If price is below marginal cost, then generation is zero. If price is equal to marginal cost, we assume that each generator supplies the same fraction of their capacity α_{sit}^r, where $0 < \alpha_{sit}^R < 1$. With a carbon policy α_{sit}^r may need to be redefined such that the carbon market clears.

Panel A. Both states CAT

Panel B. Both states rate standard



Panel C. One state CAT one state rate: Efficient dispatch

Panel D. One state CAT one state rate: Inefficient dispatch

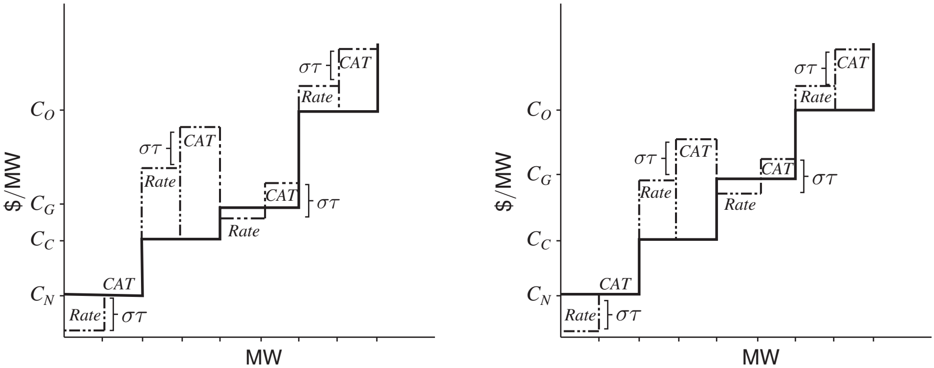


Figure 1. Full Marginal Costs under Different Regulatory Regimes

merit order of coal- and gas-fired generation. Market supply would be found from Figure 1 by reordering the technologies according to their full marginal costs.

If all states adopt CAT regulations, the equilibrium electricity price in hour t is characterized by equation (1) with this full marginal cost. Generator profits are given by

$$(4) \qquad \pi_{si}^{CAT} \equiv \sum_t \left(p_t^{CAT} - FMC_{si}^{CAT}\right) q_{sit}^{CAT} = \sum_t \left(p_t^{CAT} - c_i - \beta_i p_{cs}\right) q_{sit}^{CAT}.$$

Thus generator profits do not include carbon market revenue, e.g., permits are auctioned not grandfathered, and welfare calculations must account for the carbon market revenue separately.[15]

To complete the characterization of the CAT equilibrium, we describe equilibrium in the market for carbon certificates. Since the supply of permits is fixed at

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[15] Under CAT, stakeholder benefits depend on the distribution of the carbon market revenue. Throughout, we account for the CAT carbon market revenue separately rather than assign it to either consumers (ratepayers) or producers because its distribution is a question of policy.

E_s, demand equals supply in state s when $\sum_i \sum_t \beta_i q_{sit}^{CAT} = E_s$. Note that a higher carbon price p_{cs} decreases carbon emissions, so there exists a carbon price which clears the carbon market.

The above characterization of the market equilibrium under CAT assumes each state has its own independent regulation. The model is extended to allow carbon trading between states. If two states allow carbon trading, then the price of carbon certificates is equal across both states, and the carbon market equilibrium is characterized by emissions equal to the aggregate cap. It is well known that allowing trading across cap-and-trade programs reduces the cost of achieving the aggregate emissions target. Furthermore, the equilibrium is invariant to the distribution of the cap across the states, i.e., only the aggregate cap is relevant.

B. *Rate Standard Regulation*

Next we characterize equilibrium under a rate standard. A rate standard limits the aggregate carbon emissions per MWh of electricity and can be tradeable (see Holland, Hughes, and Knittel 2009). Let σ_s be allowed emissions per MWh in state s. Any technology whose emissions rate, β_i, exceeds the standard would be required to purchase certificates per MWh based on the amount by which its emissions rate exceeds the standard. Conversely, any technology whose emissions rate is below the standard could sell certificates based on the difference between their emissions rate and the standard. Let p_{cs} be the price of tradeable certificates for one unit of carbon emissions. Thus the rate standard changes the full marginal cost of generators based on whether they are buying or selling permits. In particular, the rate standard changes the full marginal cost of technology i in state s from c_i to $c_i + (\beta_i - \sigma_s) p_{cs}$. Note that full marginal costs may be higher or lower than *BAU* depending on whether $\beta_i - \sigma_s$ is positive or negative, i.e., depending on whether a technology buys or sells certificates.

These full marginal costs are illustrated in panel B of Figure 1 for the four technologies. In the hypothetical illustrated, the rate standard reduces the full marginal costs of (i.e., subsidizes) nuclear- and gas-fired generation, but increases the full marginal costs of coal- and oil-fired generation. As with the CAT, the merit order under rate standards as illustrated switches gas and coal, i.e., gas-fired generation is used before coal-fired generation as demand increases.

Intuitively, the rate standard is equivalent to a tax of $\beta_i p_{cs}$ combined with a subsidy of $\sigma_s p_{cs}$. Whether the rate standard implicitly taxes or subsidizes generation depends on comparing the emissions rate with the standard. The implicit output subsidy has an efficiency cost (see Holland, Hughes, and Knittel 2009) but can also serve as a defensive mechanism to prevent leakage.[16]

If all states adopt rate standards, the equilibrium electricity price in hour t is characterized by equation (1) with these full marginal costs. Profits are

$$(5) \qquad \pi_{si}^{RS} \equiv \sum_t \left(p_t^{RS} - FMC_{si}^{RS}\right) q_{sit}^{RS} = \sum_t \left(p_t^{RS} - c_i - (\beta_i - \sigma_s) p_{cs}\right) q_{sit}^{RS}.$$

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[16] Output-based allocations are a similar defensive mechanism to prevent leakage (see Fischer 2001).

As above we assume that generators are not given permits. However generators with relatively cleaner technologies, for which $\beta_i < \sigma_s$, create permits by generating electricity. In this case, the term $-(\beta_i - \sigma_s)$ is positive and captures the revenue which would arise from selling carbon credits. Thus the profits capture all revenue streams and there is no carbon market revenue to be accounted for separately.

To complete the characterization of the equilibrium, we describe the market for carbon certificates. The demand for carbon certificates is determined by the amount each technology exceeds the standard and by how much electricity is generated from each technology. For example, demand for certificates in state s from technology i is $\sum_t (\beta_i - \sigma_s) q_{sit}^{RS}$ if $\beta_i > \sigma_s$. Similarly, supply in state s from technology i is $\sum_t (\sigma_s - \beta_i) q_{sit}^{RS}$ if $\beta_i < \sigma_s$. Because demand less supply equals zero in equilibrium, the carbon market equilibrium is characterized by $\sum_i \sum_t (\beta_i - \sigma_s) q_{sit}^{RS} = 0$. Note that a higher carbon price p_{cs} decreases demand and increases supply for carbon certificates, so there exists a carbon price which clears the carbon market. Note also that the equilibrium condition can be written to show that the aggregate carbon emissions rate exactly equals the rate standard in equilibrium.

The model can be readily extended to analyze two states who combine their rate standards through carbon trading. Suppose the states s and s' allow carbon certificates to be freely traded between the states. Then the prices of the certificates are equal, i.e., $p_{cs} = p_{cs'}$, and the equilibrium condition is that demand across both states equals supply across both states. Setting demand minus supply equal to zero, we can characterize the carbon market equilibrium by

$$(6) \qquad \sum_i \sum_t (\beta_i - \sigma_s) q_{sit}^{RS} + \sum_i \sum_t (\beta_i - \sigma_{s'}) q_{s'it}^{RS} = 0.$$

This equilibrium condition can be written to show that the aggregate carbon emissions rate equals a weighted average of the allowed emissions rates across the states where the weights depend on generation.

In addition to trading carbon, which equates the carbon prices, states may also wish to harmonize their rate standards, i.e., to set $\sigma_s = \sigma_{s'}$. Note that if states do *not* harmonize their rate standards, then the full marginal costs of identical generators can be different across states even if carbon prices are the same. In order to avoid this additional inefficiency, states would need to harmonize their rate standards as well as to allow carbon trading.

Combining rate standards across states does not have the efficiency justification of combining CAT regulations. Combining CATs across states allows the same aggregate emissions target to be attained at lower cost. Combining rate standards across states does reduce costs, but it also means that the emissions target changes: both the aggregate emissions and the aggregate emissions rate are changed by combining rate standards in two states.

C. *Mixed CATs and Rate Regulation*

Finally, we consider the case of *mixed regulation* in which some states adopt CATs and other states adopt rate standards. Under the Clean Power Plan proposals, states can choose what type of regulation to adopt and a mixture of CATs and rate standards could result. The model is readily extended to mixed regulation. In particular, the equilibrium electricity price is found from the set defined in equation (1) where the full marginal costs are $c_i + \beta_i p_{cs}$ in a CAT state and $c_i + (\beta_i - \sigma_s) p_{cs}$ in a rate standard state.

In theory, states could allow carbon trading across CATs and rate standards.[17] Generating one MWh from any relatively clean plant under a rate standard creates $\sigma_s - \beta_i$ permits, which are simply tons of carbon. These permits can then be purchased by relatively dirty generators under a rate standard or any generator under a CAT. If state s has a CAT and state s' has a rate standard, trading equates the price of carbon in each state, i.e., sets $p_{cs} = p_{cs'}$. Setting the difference between aggregate certificate demand and supply equal to zero implies that the equilibrium certificate price is characterized by

$$(7) \qquad \sum_i \sum_t \beta_i q_{sit}^{RS} - E_s + \sum_i \sum_t (\beta_i - \sigma_{s'}) q_{s'it}^{RS} = 0.$$

This condition does not have a clear interpretation either as a cap or an emissions rate constraint.

D. *Theoretical Results*

We first compare the merit orders under the different regulations. We define *efficient supply* as the merit order which minimizes full social costs for any given level of generation. Note that efficient supply may not result in efficiency if the level of generation is inefficient. Our first result describes efficient supply; we then address efficiency in a corollary. All proofs are in the online Appendix.

RESULT 1 (Efficient Supply): The merit order is efficient (full social costs are minimized):

(i) if all states adopt CATs and p_{cs} is sufficiently close to τ for all s;

(ii) if all states adopt rate standards, p_{cs} is sufficiently close to τ for all s, and σ_s is sufficiently close to σ for all s; or

(iii) if there is mixed regulation, p_{cs} is sufficiently close to τ for all s, σ_s is sufficiently close to σ for all s, and $|c_i + \beta_i \tau - c_j - \beta_j \tau| > \sigma \tau$ for all i and j.

This result shows sufficient conditions for the efficiency of supply. Importantly, the sufficient conditions become increasingly stringent across the regulations.

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[17] The Clean Power Plan discourages trading across regimes and none of our simulations model carbon trading across regimes.

For CATs, supply is efficient if the carbon price equals (or is close to) the social cost of carbon. Intuitively, the CAT can implement Pigouvian pricing if the cap is sufficiently stringent, but not too stringent.

For rate standards, supply can also be efficient. For a given carbon price, the CAT and rate standard induce the same merit order since $c_i + (\beta_i - \sigma_s) p_{cs} < c_{i'} + (\beta_{i'} - \sigma_s) p_{cs}$ if and only if $c_i + \beta_i p_{cs} < c_{i'} + \beta_{i'} p_{cs}$. Intuitively, the rate standard can induce the correct relative prices across the technologies because it simply shifts the full marginal costs down by a constant. However, supply efficiency for a rate standard requires that carbon prices equal the social cost of carbon *and* that the rate standards be equal across states. Note that these sufficient conditions will not be ensured by carbon trading alone but would also require explicit harmonization of the rate standards across states. Thus the sufficient conditions are more strict for rate standards than for CAT.

Surprisingly, Result 1 (iii) shows that mixed regulation can also attain the efficient supply but only under more stringent conditions. This result is illustrated in panel C of Figure 1 for four technologies where some of each technology is subject to a CAT and some is subject to a rate standard of σ and the carbon price is τ. Note that within each technology, the implicit subsidy of the rate standard lowers the full marginal cost by $\sigma\tau$, so the rate-standard technology is dispatched first, e.g., gas under the rate standard is dispatched before gas under the CAT. As illustrated, the merit order is efficient, because all the gas-fired generation is used before the coal-fired generation as demand increases.

However, the efficiency of supply only occurs because the full marginal costs are sufficiently different. If the full marginal costs are close, i.e., if $|c_C + \beta_C \tau - c_G - \beta_G \tau| < \sigma\tau$, then the merit order is not efficient. As illustrated in panel D of Figure 1 the full marginal costs are sufficiently close that the merit order is rate-standard gas, followed by rate-standard coal, then CAT gas, and then CAT coal. This merit order is "scrambled," i.e., inefficient, because the full marginal social cost of gas-fired generation is less than the full marginal social cost of coal.[18]

Result 1 also highlights the importance of coordination across states. For CATs, all carbon prices need to be sufficiently close to τ, which can be ensured by carbon trading and a correct overall cap. Note that with carbon trading the distribution of the cap across states is irrelevant for efficiency of supply. With rate standards, trading can also ensure that carbon prices are equal across states. However, now the standards must be set equally across states in order for the merit order to be efficient, i.e., the distribution of the rate standards across the states is crucial. The result also shows an additional inefficiency if states fail to coordinate on a CAT or a rate standard.

This result also emphasizes the importance of carbon prices. Importantly, efficient supply depends on the carbon price being sufficiently close to τ, but does not depend on the target emissions level or the target emissions rate. Thus, to attain efficient supply, the regulator would need to adjust the emissions cap or target emissions rate

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[18] This inefficiency from mixed regulation is limited because it only arises if full marginal costs are sufficiently close, i.e., if costs are small from the wrong merit order.

to maintain the carbon price equal to τ. Unfortunately, the Clean Power Plan specifies emissions rate targets rather than carbon price targets.

Although efficient supply is necessary for the overall efficiency of a regulation, it is not sufficient as the following corollary makes clear.

COROLLARY 1 (Efficiency): *If demand is perfectly inelastic, then CATs, rate standards, or mixed regulation achieve efficiency if the merit order is efficient.*

If demand is not perfectly inelastic, then CAT regulations achieve efficiency if $p_{cs} = \tau$ *for all s. Rate standards and mixed regulation do not achieve efficiency.*

This corollary, which demonstrates the superiority of CAT, echoes earlier results in the literature (e.g., see Helfand 1991; Kwoka 1983; Holland, Hughes, and Knittel 2009). If demand is perfectly inelastic, then there is no consumption inefficiency and efficiency only requires efficient supply. However, if demand is not perfectly inelastic, then only a CAT regulation with a carbon price of τ can attain the first best.[19]

Given the importance of equal carbon prices in Result 1, the next result addresses the benefits from carbon trading, which equates carbon prices across regions.

RESULT 2 (Carbon Trading): Trading carbon between states reduces costs. Trading between states with CATs holds aggregate emissions constant. Trading between states with rate standards may cause aggregate emissions to increase or decrease.

Result 2 shows that although carbon trading does reduce costs, it may not have clear efficiency benefits. It is well known that under CAT aggregate emissions are held constant and thus a reduction in costs leads to a clear efficiency gain, i.e., CAT is cost effective.

Under rate standards, Holland, Hughes, and Knittel (2009) show aggregate emissions could increase or decrease, and thus the welfare effects of carbon trading are indeterminate. For example, consider a state with an inelastic supply of relatively clean generation but elastic supply of dirty generation. This state will primarily respond by reducing dirty generation, which would lower overall emissions. If this state trades carbon with a state with an elastic supply of relatively clean (but not zero carbon) generation, then the resulting increase in relatively clean generation could lead to an overall increase in emissions. The welfare effects would need to compare any cost savings from carbon trading with this increase in emissions and hence are ambiguous.

We next compare the equilibrium outcomes across policies in which all states adopt the same policy. We analyze electricity prices, consumer surplus, and profits to "uncovered generators," namely, generators which are not covered by the regulation, e.g., renewables or distributed generation.

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[19] Holland (2012) shows that rate standards can attain the first best if they are coupled with an electricity tax of $\sigma\tau$. Furthermore, he shows that in a second-best setting all these policies may fail to attain efficiency and the best policy is not theoretically clear.

RESULT 3 (Prices, Consumer Surplus, and Uncovered Generator Profits): For a given carbon price $p_{cs} > 0$:

(i) electricity prices are higher under CATs than under either rate standards or no regulation, i.e., $p_t^{CAT} \geq p_t^{RS}$ and $p_t^{CAT} \geq p_t^{BAU}$, and electricity prices under rate standards or under mixed regulation can be either higher or lower than under no regulation;

(ii) consumer surplus is lower under CATs than under either rate standards or no regulation, i.e., $CS^{CAT} \leq CS^{RS}$ and $CS^{CAT} \leq CS^{BAU}$, and consumer surplus under rate standards or under mixed regulation can be either higher or lower than under no regulation; and

(iii) profits for uncovered generation are higher under CATs than under either rate standards or no regulation, and profits for uncovered generation under rate standards or under mixed regulation can be either higher or lower than under no regulation.

Result 3 shows that a rate standard will generally be preferred by consumers, but that uncovered generators will generally prefer a CAT. The intuition follows directly from the electricity prices. For a given carbon price, the result shows that electricity prices are higher under a CAT but can be higher or lower than BAU prices under rate standards. These price comparisons follow from a comparison of the full marginal costs under the policies. Since full marginal costs are higher under CAT than under rate standards or BAU, the electricity price is higher. Similarly, since the full marginal costs under rate standards can be higher or lower than under BAU, the electricity prices are similarly higher or lower. The results on consumer surplus and profits of uncovered generation follow directly from the result on prices.

The result on uncovered generation is important since significant generation capacity may not be covered by the Clean Power Plan, e.g., hydro, nuclear, and some combined heat and power. The result shows that these uncovered generators will prefer CAT regulation because they would benefit from the higher electricity prices. The effect is somewhat different for "dirty" and "clean" uncovered generators. For dirty uncovered generators, the benefit arises from the higher electricity prices and because the lack of carbon regulation does not increase their costs. For clean uncovered generators, the difference arises from the higher electricity prices and because the lack of carbon regulation does not *decrease* their costs under rate standards. The inability to sell carbon credits under a rate standard implies that uncovered clean generation prefers CAT. Note that this result also implies that incentives are strongest under CAT for new clean generation and for efficiency improvements, both of which might be uncovered by the Clean Power Plan.

The result also has important implications for investment incentives. Investment will occur in the most profitable locations. New fossil fuel-fired generation may be "uncovered" since it is subject to other regulations, e.g., Section 111(b) of the Clean Air Act, and may not be subject to the Clean Power Plan. Small combined heat and power will also likely not be covered by the Clean Power Plan. Efficiency improvements may also not be covered. The result implies that there would be more investment in uncovered generation under CAT regulation than under rate standards.

We next analyze the incentives for states to adopt either CATs or rate standards by analyzing the outcomes if states coordinate on either a single CAT or a single rate standard. To focus the analysis, we assume additionally that carbon prices equal τ and rate standards are equal across states, i.e., we assume efficient supply.

RESULT 4 (Adoption Incentives of a Coalition): Suppose that all states adopt the same regulation, i.e., all states have a unified CAT or unified rate standard. Suppose further that the CAT or rate standard results in a carbon price equal to the social cost of carbon across both regimes and across all states, i.e., $p_{cs} = \tau$ for all s, and that rate standards are equal across states, i.e., $\sigma_s = \sigma$ for every s. The following results hold:

(i) $p_t^{CAT} \leq p_t^{RS} + \sigma\tau$ for all t;

(ii) $q_{sit}^{CAT} \leq q_{sit}^{RS}$ for all s, i, and t;

(iii) $\pi_{si}^{CAT} \leq \pi_{si}^{RS}$ for all s and i;

(iv) $W^{CAT} \geq W^{RS}$; and

(v) $TR^{CAT} + \tau\left(Carbon^{RS} - Carbon^{CAT}\right) \geq \left(CS^{RS} - CS^{CAT}\right) + \left(\pi^{RS} - \pi^{CAT}\right)$.

If additionally we assume that demand is perfectly inelastic, then each of the weak inequalities above is an equality.

When states act in a coalition, this result shows that although welfare is maximized under CAT instead of a rate standard, the direct revenue from carbon permit sales may not be enough to compensate consumers and producers for lost surplus and profit. The intuition follows from noting that under these assumptions the merit order is unchanged and full marginal costs are lower by $\sigma\tau$ under the rate standard, which implies that the market supply is simply shifted down by $\sigma\tau$. If demand were perfectly inelastic, equilibrium prices would fall by exactly this amount. If demand is not perfectly inelastic, then a price which is lower by $\sigma\tau$ could result in excess demand. Thus the price difference between the CAT and rate standard is at most $\sigma\tau$.

Because the market supply shifts down, generation must be (weakly) higher under the rate standard for each generator for each hour (Result 4(ii)). This has additional implications for carbon emissions and generation costs, which are both higher under the rate standard.

The comparison of profits in Result 4(iii) follows because the market supply shifts down by $\sigma\tau$ and the price falls by at most $\sigma\tau$. Thus producer surplus (i.e., generator profit) is higher under the rate standard for each generator.

The inefficiency of rate standards, described in Corollary 1, implies the result on welfare in Result 4(iv). Rewriting this in Result 4(v) shows that the sum of carbon market revenue and the increase in carbon market damages exceeds the sum of the increases in consumer surplus and profit under rate standards.

With perfectly inelastic demand this equality becomes $CS^{CAT} + TR^{CAT} = CS^{RS}$, which shows that the gain in consumer surplus from a rate standard is exactly the foregone carbon market revenue TR^{CAT}. In this case, the carbon market revenue is exactly sufficient to compensate consumers for the lost consumer surplus under CATs.

If demand is not perfectly inelastic, the inequality in (v) is less informative about the ability of carbon market revenue to compensate consumers and producers for their losses under the CAT. In particular, it shows that carbon market revenue plus the additional carbon damages would be sufficient to compensate both producers and consumers for their losses under the CAT. However, the result suggests that it is an empirical question whether or not carbon market revenue by itself will be sufficient to compensate both producers and consumers for their losses under CAT.

E. *Incentives for Regulatory Choice*

We now turn to the adoption incentives of an individual state. In particular the question of how a state's choice interacts with other states' choices to influence economic outcomes. This question could be directly addressed by the previous results if carbon prices were exogenous to the specific mechanism, for example, if states adjusted the CATs or rate standards so that the carbon prices always equaled the social cost of carbon.

For exogenous carbon prices, Result 4 is a good guide to the adoption incentives of a single state.[20] As in Result 4 (i), if the state adopted a rate standard instead of a CAT, electricity prices would be lower in any hour in which that state's generators were marginal, but the electricity price would be lower by at most $\sigma_s \tau$. Since generators' costs would be lower by $\sigma_s \tau$, generators' profits would be higher under the rate standard. With lower electricity prices, consumer surplus would also be higher under a rate standard. Thus consumers and covered generators would prefer that their state adopt the rate standard regardless of what other states do. In other words, adoption of a rate standard would be a dominant strategy from the perspective of covered generators or consumers. On the other hand, carbon market revenue and higher electricity prices from CAT imply that CAT adoption would be a dominant strategy from the perspective of government revenues and of uncovered generators. Thus, with fixed carbon prices, some perspectives would have a dominant strategy for adoption of a CAT but others would have a dominant strategy for adoption of a rate standard.

Since the Clean Power Plan specifies emissions and emissions rates rather than carbon price targets, carbon prices are likely endogenous to the regulatory choices of neighboring states. This complicates a single state's adoption decision. We assess these incentives more thoroughly in our numerical simulations; however, a few examples illustrate the possibilities. Suppose a state were to consider a CAT when all its neighbors adopt a rate standard. Without a carbon price response, the full marginal costs would be higher under the CAT and thus the state's generators would be

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[20] Result 5 in online Appendix A extends Result 4 to analyze the adoption incentives of a single state assuming carbon prices are fixed at τ.

dispatched less frequently, and there would be an excess supply of carbon permits. This implies that the state's carbon price would be lower if it adopted a CAT instead of an equivalent rate standard, thereby making CAT more attractive from some perspectives.[21] On the other hand, a state choosing a rate standard when its neighbors are under CAT could experience either an increase or decrease in its carbon price, depending upon the mix of available supply in that state. For example if the rate state had excess "clean" generation capacity (e.g., gas generation with an emissions rate below the state's standard) then increasing exports from those clean sources would relax the rate standard constraint and hence lower carbon prices. Finally, we can construct an example where adoption of mixed regulations lowers carbon prices for both CAT and rate states. Compliance costs and electricity prices would then be lower compared to a uniform CAT scheme.

A state's adoption incentives will hence involve a combination of carbon price effects in addition to the effects outlined in Result 4. To assess the direction and magnitude of these effects, we turn to a numerical simulation model.

III. Numerical Simulations

The theoretical model describes the inefficiencies which can result when states choose CAT regulation or rate standards across an integrated product market. As described above, there are several additional considerations to the actual Clean Power Plan that are difficult to capture in a theoretical model, including the heterogeneity of both supply technologies and emissions limits across states, and importantly, the endogeneity of carbon prices to a market's choice of regulatory mechanism. We approach this richer set of issues using numerical simulation methods applied in the context of the electricity market in the western United States.[22] In this section, we present the simulation model and the data used to parameterize the model. Additional details on the numerical simulation are in online Appendix C.

A. *Optimization Model and Constraints*

Because we assume firms act in a manner consistent with perfect competition in both the electricity and emissions permit markets, market equilibrium is equivalent to the solution of a social planner's problem. Our social planner's problem maximizes gross consumer surplus less generation costs subject to various operating constraints. Using the notation developed above, the planner's objective is thus:[23]

$$\max_{q_{sit}} CS + \sum_{s}\sum_{i}\sum_{t}(p_t - c_i)\,q_{sit}. \tag{8}$$

The generation costs in equation (8) are comprised of the marginal operating costs for existing and new generation (taken from sources described in the online

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[21] Intuitively, the state can achieve compliance through importing.

[22] We utilize an electricity transmission and supply model similar to that used in Bushnell and Chen (2012); and Bushnell, Chen, and Zaragoza-Watkins (2014).

[23] The objective does not consider carbon damages, which are addressed through the constraints.

Appendix) and annualized capital costs for new generation capacity. Maximization of equation (8) is subject to generation, transmission, and policy constraints. Generation constraints reflect installed capacity adjusted proportionally for the probability of a forced outage of each unit from the generator availability data system.

The model allows for market-based investment in new natural gas and wind generation capacity. The availability of a new wind resource is subject to an hourly generation profile that is specific to each region and taken from data sources described in the online Appendix. For both technologies, the objective function in equation (8) includes an annualized per-MW cost of capital, and the hourly output and marginal cost of new units. The resulting equilibrium condition equates the capital cost to the net operating profit of a technology, or $C_i \times K_i = \sum_t q_{it} \times (p_t - FMC_{si})$, where i is a technology with capital cost C_i and full marginal cost (including carbon) FMC_{si}, and $q_{it} \leq K_i \times avail_t$ is the output of technology i, which is constrained to not exceed the installed capacity (adjusted for availability).

Our transmission constraints replicate centralized locational marginal pricing (LMP). Any LMP price differences are arbitraged away subject to the constraints of the transmission network. Optimization of equation (8) is therefore subject to constraints on the flows between five transmission regions represented in our model. These constraints are governed by existing line capacities. See online Appendix C3 for more detail on our modeling of transmission constraints. Transmission fees and line losses are implicitly captured by our BAU simulation and assumed to be constant across the different policy scenarios.

The carbon policies are modeled with additional constraints. BAU is modeled by optimizing equation (8) subject to the generation and transmission constraints. Under CAT regulation in state s, total emissions in the state must also be less than allowed emissions, i.e., the policy constraint is $\sum_i \sum_t \beta_i q_{sit} \leq E_s$. If two states harmonize their CAT regulations through emissions trading, aggregate emissions across the two states must be less than total allowed emissions. The shadow values of the constraints are the carbon prices that would result from implementation with market mechanisms. Similarly, if state s adopts a rate standard, then the emissions rate in the state must be less than the allowed emissions rate. If two states harmonize their rate standards, then the constraint is on the aggregate emissions rate. Note that this is equivalent to allowing carbon trading *plus* harmonizing the allowed emissions rates. The shadow values are again the carbon prices.[24] In cases where both rate and CAT standards coexist we assume no trading of emissions credits across regimes.

B. *Data Sources and Assumptions*

The model uses cost and market data from the year 2007. Electricity demand levels and market prices for each region and hour are taken from public data sources described in online Appendix C. For tractability, hourly data are aggregated into representative periods which are weighted to calibrate market outcomes in terms of annual statistics. We assume linear demand where the intercept in each time period

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[24] We write the rate standard constraints as $\sum_i \sum_t \beta_i q_{sit} \leq \sigma_s \sum_i \sum_t q_{sit}$ so that the shadow value is in dollars per ton of carbon.

is determined by the mean actual hourly electricity price and consumption level during that time period.[25] Because electricity demand is extremely inelastic, we utilize an extremely low value for the slopes of the linear demand curve.[26] The slope of the demand curve is set so that the median elasticity in each region is -0.05.[27] Consumer surplus is, as usual, the area under the demand and above the price.[28]

We explicitly model all fossil-fired generation monitored by the EPA's continuous emissions monitoring system (CEMS). These constitute almost all the units whose emissions would be regulated under the Clean Power Plan, i.e., covered generation. The marginal cost of a modeled generation unit is assumed to be the sum of its fuel and variable operation and maintenance (VO&M) costs, taken from data sources described in online Appendix C. We calculate fuel costs for each unit as a constant heat rate (mmBtu/MWh) multiplied by regional average fuel price, up to the capacity of the unit. We use unit average heat rates and regional average fuel prices taken from the Platts PowerDat dataset. Emissions rates, measured as tons CO_2/MWh, are based upon the fuel-efficiency (heat rate) of a plant and the CO_2 intensity of the fuel burned by that plant.

We first use natural gas prices from 2007 to establish if the simulation reasonably captures generation and emissions totals over western states. Because we separately calibrate demand and supply before aggregating demand, our simulation does not exactly replicate 2007 market outcomes. Online Appendix Table D9 shows that our predicted uncovered generation, covered generation, and emissions each match actual 2007 levels to within 2 percent. The results reported here utilize natural gas prices that are, on average, \$2/mcf lower, to better capture current fuel price conditions.

Investment in our simulations is based on information from the National Renewable Energy Laboratory. We assume the annualized capital cost of new natural gas combined-cycle units is \$100 KW-yr. Operating costs for the combined-cycle gas c_{st} depend on natural gas prices and are assumed to be \$48/MWh under 2007 gas prices and \$32/MWh under current gas prices. The annualized capital cost of a new wind turbine is \$200 KW-yr. We assume that wind turbines have no marginal operating costs, but their output is constrained by wind availability. We use data on projected capacity factors of new wind plants taken from a WECC dataset used in Bushnell (2010). These capacity factors, which capture the intermittency of wind generation, vary by every hour and subregion in the simulation. The average capacity factor for a new wind plant is about 35 percent. The capacity factors vary considerably by region, approaching 40 percent in the Rocky Mountains but averaging only 28 percent in the Southwest.

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[25] The intercept is the sum of mean consumption and the product of the mean price and demand slope.

[26] The inelasticity of demand reflects in part the imperfect pass-through of wholesale prices to end-use electricity consumers.

[27] The low elasticity is chosen in part to reflect the imperfect pass-through of wholesale prices to retail rates. Because the market is modeled as perfectly competitive, the results are relatively insensitive to the elasticity assumption, as price is set at the marginal cost of system generation and the range of prices is relatively modest. We discuss this assumption in the online Appendix.

[28] Inelastic linear demand implies unrealistically large consumer surplus triangles, which we arbitrarily truncate above \$100 per MWh. Because we are mainly interested in changes in consumer surplus relative to BAU, this assumption is unimportant. For state-level demand and consumer surplus calculations, we use EIA data on annual consumption by state to calculate the fraction of a region's demand that is attributable to a given state. This approximation assumes that the hourly distribution of regional demand amongst states is the same as the annual average.

Unfortunately, we lack data on the hourly generation from some other sources, namely, renewable resources, hydroelectric resources, nuclear, combined heat and power, and other small thermal resources. We infer aggregate hourly generation from these sources from the difference between regional hourly demand and fossil-fired generation after accounting for net imports. These sources, which primarily have very low or zero marginal costs, are assumed to have the same hourly generation in all of our simulations. We do not observe state imports for a given hour. Instead net imports are aggregated to the regional level within the western interconnection (WECC) and approximated from data on the hourly flow over key transmission lines between regions.

In some results we disaggregate the outcomes for supply between generation sources covered under the Clean Power Plan and "uncovered" sources. Covered sources include all modeled fossil fuel generation. For the CPP, the EPA has proposed a formula that gives credit for output from new nuclear capacity as well as credits for renewable generation and energy efficiency. Such sources may be eligible to earn emissions credit payments by virtue of their emissions rates being below the emissions rate standard. However because of our data limitations we include all non-thermal sources in our "uncovered" category in the results below.

To model CO_2 regulation under the CPP, we convert the EPA's interim goals, which average 2022–2029 targets, into the equivalent rate and CAT standards for our simulation. To do this we assume that the carbon reductions would be equivalent if the electricity quantities were the same. In other words, we establish a baseline emissions quantity and MWh output for each state, which converts into a baseline emissions rate by dividing the former by the latter. We apply the EPA's mandated reduction percentage to this baseline emissions rate and calculate the rate standard for each state. For example, Arizona's emissions rate is required to be reduced to 75.6 percent of its baseline emissions rate, so Arizona's rate standard is $0.756 \times (1.3 \times 10^{11} \text{ lbs. } CO_2)/(8.6 \times 10^7 \text{ MWh})$.

The equivalent CAT regulation is the baseline emissions reduced by the same percentage. Our main scenarios assume new generation is included under the CAT regulation (but not the rate standard). To be consistent with the EPA's calculations for new source complements, we increase the cap described above by an additional 2.4 percent, which is the average increase allowed. For example, Arizona's cap is $0.756 \times (1.3 \times 10^{11} \text{ lbs. } CO_2) \times 1.024$.

C. *Caveats and Limitations*

Our simulations capture many of the key elements that influence state choices and outcomes under the Clean Power Plan, such as short-run generation costs, transmission constraints, and investment in natural gas and wind generation. That said, there are some limitations to the model. We do not explicitly consider the opportunities for abatement from increasing the efficiency of coal-fired power plants or from state investments in energy efficiency. Further, we do not explicitly model other state level policies, such as renewable portfolio standards, or federal policies such as the production and investment tax credits that might influence the specific compliance strategy of a state. Finally, the generation mix has changed somewhat since 2007, primarily through investment in new gas-fired generation. To the extent that these factors reduce the need for relatively dirty generation, they lower compliance costs. However, the relative effects on costs across the policies are less clear.

We also make several simplifying assumptions in reporting our simulation results. To calculate carbon damages, we use a social cost of carbon equal to \$43/MT, consistent with EPA regulatory filings. We do not include damages from other co-pollutants. Including co-benefits would increase welfare relative to the status quo in all policy scenarios and could change the scenario rankings. Next, while we separately report producer and consumer surplus, the division of surplus likely depends on whether generation in a given state falls under rate regulation. In regulated states, producer surplus may largely accrue to consumers. Consumer surplus is calculated and reported for the wholesale electricity markets. This implicitly assumes wholesale prices are eventually passed through to end users but diluted to some extent by the regulation of retail rates. The dilution of wholesale price fluctuations is one reason we utilize a relatively low demand elasticity. We also do not model the myriad inefficiencies of retail electricity pricing. For instance, if retail prices are inefficiently high, a rate standard that does not increase electricity prices as much may be less inefficient. Finally, our calculations abstract away from tax interaction effects and double-dividend style benefits (Goulder, Parry, and Burtraw 1997), which may be larger under CAT compared to rate standards. To get a sense of the size of the potential double-dividend, we separately report carbon market revenue, which could in principle be given to generators, consumers or taxpayers.

IV. Simulation Results

We present simulation results from scenarios that span the states' policy options under the CPP, e.g., rate standard versus CAT regulation and coordinated versus mixed regulation. To reduce the number of possible policy combinations, some results collect states into possible regional groups. We consider a group of "Coastal" states, (California, Oregon, and Washington) and "Inland" states: Arizona, Colorado, Idaho, Montana, New Mexico, Nevada, Wyoming, and Utah. This division is somewhat reflective of current policy discussions.[29]

Following the theory model, we first discuss the supply-side effects of regulations on the generation merit order. Then, we analyze equilibrium outcomes under each policy and incentives to form coalitions. Finally, we explore incentives for investment in new capacity under different regulations.

A. *Supply-Side Effects*

Figures 2–5 illustrate how various policy options affect the full marginal costs and how the merit order can be scrambled. Figure 2 compares the full marginal costs of existing fossil fuel generation units under West-wide CAT and rate standards

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[29] California, Oregon, and Washington are currently members of the Pacific Coast Collaborative, which seeks cooperative action in mitigating greenhouse gas emissions. They are the only WECC states participating in this initiative.

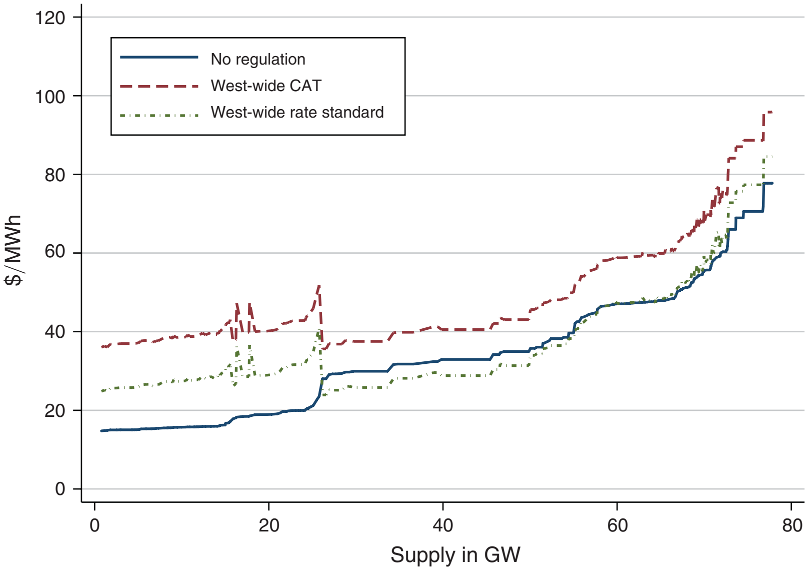

Figure 2. Full Marginal Costs: BAU and West-Wide CAT and Rate Standards

Note: Generating units sorted on x-axis by marginal costs under BAU (Scenario 0).

to the market supply under BAU (i.e., the generating units are sorted along the x-axis by BAU marginal costs). The generating units to the left of 23 GW are primarily coal-fired and the generating units to the right of 23 GW are gas-fired. The West-wide CAT increases the full marginal costs of the units in proportion to their carbon emissions. Because coal is dirtier than gas, this changes the merit order, and some gas-fired generation is now cheaper than coal-fired generation and would be used first as demand increases.

The West-wide rate standard also increases costs in proportion to carbon emissions, but includes an implicit output subsidy. The net effect increases the full marginal costs of the coal-fired generation but *decreases* the full marginal costs of gas-fired generation with emissions rates below the standard. Both the West-wide CAT and rate standard achieve approximately the same relative ordering of generation. This is consistent with theoretical Result 1 that both policies can eliminate the supply-side inefficiency. However, full marginal costs are too low under the rate standard.[30]

Figure 3 compares the coal and gas full marginal costs under state-by-state CAT standards with the supply curve for a West-wide CAT. The state-by-state CATs lead to full marginal costs that are too high in some states (those with tight caps) and too low in other states (those with loose caps). This heterogeneity "scrambles" the merit

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[30] Our CAT simulation yields a permit price below the social cost of carbon. Under the rate standard, full marginal costs are lower than those under CAT and are often less than the unregulated case where carbon emissions are unpriced.

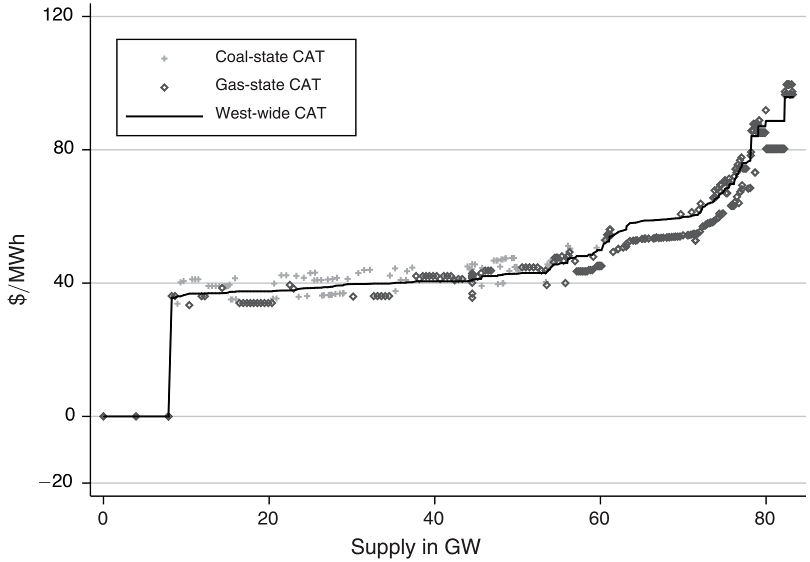

Figure 3. Full Marginal Costs: West-Wide CAT Standards and State-by-State CAT Standards

Note: Generating units sorted on *x*-axis by full marginal costs under West-wide CAT standards (Scenario 1).

order and is an additional source of inefficiency.[31] Practically speaking, this can lead to very different dispatch ordering of similar generating units, which is clearly inefficient.

Figure 4 compares the full marginal cost when regional coalitions fail to coordinate policies with the supply curve for a West-wide CAT. If Coastal states adopt a CAT standard and Inland states adopt a rate standard, the carbon prices are too low in both regions. The resulting merit order is not only scrambled, but the full marginal costs are also too low. This suggests the possibility of additional inefficiencies from mixed regulation, which we explore further below.

Finally, Figure 5 compares market supply under the West-wide CAT, West-wide rate standard, and BAU. Because wind capacity varies throughout the year, we plot a representative peak summer hour. Two features are worth noting. First, both CAT and the rate standard increase investment in wind generation, the leftmost portion of each curve, shifting out supply by about 8 GW relative to the no regulation case. Second, since CAT increases the full marginal cost of all fossil fuel generation, costs are higher than BAU for almost all generation levels despite the substantial investment in wind capacity. Because the rate standard decreases the full marginal cost of some gas generation and induces considerable wind investment, costs are often lower than BAU.

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[31] Online Appendix Figure E4 shows a similar "scrambling" of the merit order due to state-by-state rate standards.

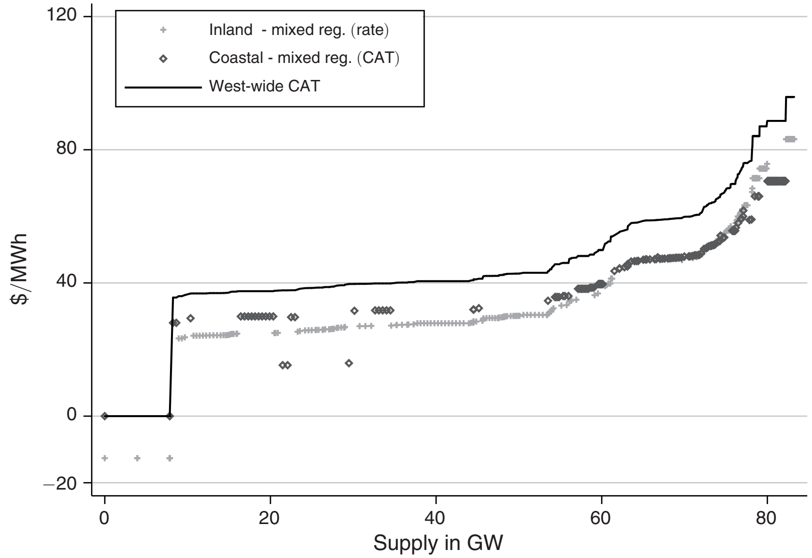

Figure 4. Full Marginal Costs: West-Wide CAT Standards and Mixed Regulation

Notes: Generating units sorted on *x*-axis by full marginal costs under West-wide CAT standards (Scenario 1). Mixed regulation has Coastal CAT standard and Inland rate standard.

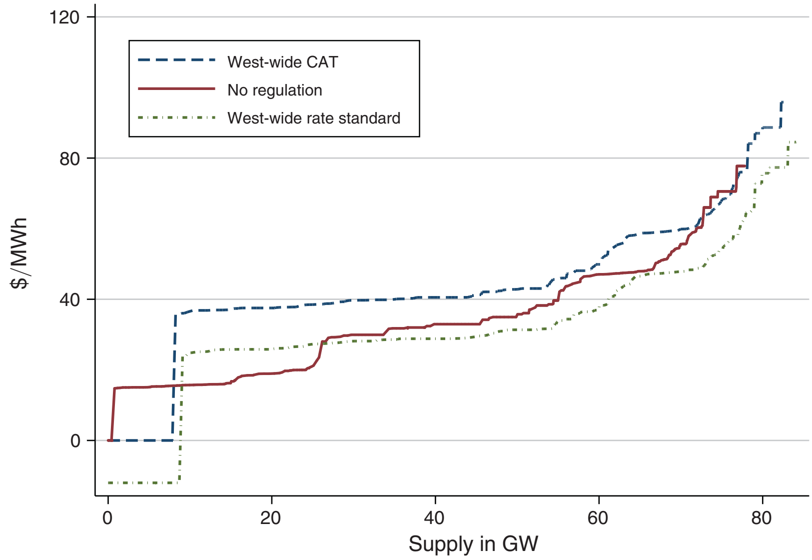

Figure 5. Market Supply with New Investment: West-Wide CAT Standards and West-Wide Rate Standards

Note: Generating units sorted on *x*-axis by full marginal costs under each policy: CAT, no regulation, or rate standard.

TABLE 1—EQUILIBRIUM OUTCOMES FOR BUSINESS AS USUAL AND EIGHT POLICY SCENARIOS

	No Reg. 0	CAT 1	CATs 2	Rate 3	Rates 4	CAT rate 5	CAT rates 6	Rate CAT 7	Rates CAT 8
Electricity price ($/MWh)	$41.83	$48.03	$47.41	$36.44	$36.09	$35.89	$35.74	$43.82	$43.81
Electricity quantity (GWh)	787,472	−4,178	−3,955	+3,780	+3,949	+3,993	+4,068	−1,389	−1,419
New natural gas gen. cap. (MW)	2,017	−2,017	−139	−2,017	−2,017	−2,017	−2,017	+179	+965
New wind gen. cap. (MW)	875	+14,550	+10,141	+17,334	+19,105	+17,130	+17,591	+8,799	+7,946
Emissions (MMT)	330.79	−70.58	−70.58	−79.11	−64.99	−65.83	−57.47	−53.52	−51.60
CAT permit price ($/MT)		$21.07	$19.83			$0.00	$0.00	$19.59	$19.51
Rate permit price ($/MT)				$21.86	$22.48	$21.00	$20.82	$9.18	$9.58
Consumer surplus ($ bn.)	$44.41	−$4.88	−$4.37	+$4.27	+$4.41	+$4.56	+$4.70	−$1.39	−$1.41
Covered generator profits ($ bn.)	$7.12	−$3.79	−$4.24	−$3.79	−$3.83	−$3.82	−$3.83	−$3.97	−$3.96
Uncovered generator profits ($ bn.)	$13.90	+$2.06	+$1.89	−$1.81	−$1.93	−$1.95	−$2.04	+$0.60	+$0.62
Transmission profits ($ bn.)	$0.18	+$0.02	−$0.03	−$0.00	+$0.14	+$0.10	+$0.12	−$0.09	−$0.08
Generation costs ($ bn.)	$11.91	+$0.92	+$1.16	+$1.48	+$1.36	+$1.26	+$1.21	+$0.96	+$0.95
Carbon market rev. ($ bn.)		+$5.48	+$5.43			+$0.00	+$0.00	+$3.86	+$3.85
Abatement cost ($ bn.)		−$1.11	−$1.32	−$1.34	−$1.21	−$1.11	−$1.05	−$1.00	−$0.99
Avg. abatement cost ($/MT)		+$15.69	+$18.74	+$16.93	+$18.64	+$16.86	+$18.26	+$18.65	+$19.21
Carbon damages ($ bn.)	$14.22	−$3.04	−$3.04	−$3.40	−$2.79	−$2.83	−$2.47	−$2.30	−$2.22
Social welfare ($ bn.)	$51.39	+$1.93	+$1.71	+$2.06	+$1.58	+$1.72	+$1.42	+$1.30	+$1.23
No new source complements	$51.39	+$2.16	+$1.95	+$2.06	+$1.58	+$1.72	+$1.42	+$1.44	+$1.34

Notes: Results from Scenarios 1–8 are reported as changes relative to Scenario 0. "+" indicates an increase and "−" indicates a decrease. "Abatement cost" is the sum of consumer surplus, profits (covered, uncovered, and transmission), and carbon market revenue. Consumer surplus is calculated using a choke price of $100/MWh. Carbon damages assume a social cost of carbon equal to $43.

B. *Equilibrium Market Impacts*

These scrambled merit orders indicate the potential for inefficiency. To assess the magnitudes of any inefficiencies, Table 1 compares equilibrium outcomes from eight policy scenarios to BAU ("No Reg" or Scenario 0). Scenarios 1 through 8 vary which states or regions operate under CAT and rate standards and whether regulations are harmonized. Online Appendix C8 presents a subset of outcomes for individual states.

First, consider the two West-wide policies: a West-wide CAT (Scenario 1) and a West-wide rate standard (Scenario 3). Consistent with theory, average electricity prices relative to BAU are higher under CAT and lower under a rate standard. As expected, electricity consumption relative to BAU is lower under CAT but higher under the rate standard. These electricity prices and consumption translate into effects on consumer surplus and generator profits that are also consistent with the theoretical results. The difference in consumer surplus between the scenarios is mostly accounted for by the carbon market revenue and higher profits to uncovered generators, thus the private surplus loss (or abatement cost) is quite similar across the two policies ($1.11 versus $1.34 billion relative to BAU).

To compare the efficiency of these two scenarios, first note that the carbon prices (marginal abatement costs) are similar ($21.07 versus $21.86 per MT), so any supply-side inefficiencies should be modest (as suggested by Figure 2). Moreover, these carbon prices are well below the social cost of carbon ($43 per MT), so both policies are reducing carbon less than would be efficient.[32] Due to the new source complements in the parameterization of the CAT, emissions reductions are actually smaller under the West-wide CAT (70.58 MMT, about 21 percent) than under the West-wide rate standard (79.11 MMT, about 24 percent). Because the emissions reduction is more modest and because the policy can be efficient, the West-wide CAT has the lowest average abatement cost of all the policies. The West-wide rate standard, by reducing carbon emissions more, actually results in the highest welfare gain ($2.06 billion relative to BAU).[33]

Relaxing the West-wide CAT by including new source complements was intended to prevent leakage to new capacity. However, loosening the cap has an efficiency cost. Modeling "No New Source Complements" shows that a West-wide CAT, which achieves the same emissions reduction as the West-wide rate standard, would result in even larger gains in social welfare ($2.16 billion relative to BAU). This illustrates the inefficiency of the West-wide rate standard.

We next turn to cases where states fail to harmonize regulations. In particular, Scenario 2 shows state-by-state CATs and Scenario 4 shows state-by-state rate standards. Due to the idiosyncracies of the state-level targets in the CPP, failure to harmonize policies results in substantial inefficiencies. Compared to the West-wide policies, state-by-state policies have higher average abatement costs ($18.74 versus $15.69 per MT, 19 percent higher and $18.64 versus $16.93 per MT, about 10 percent higher) despite the state-by-state rate standard having a smaller carbon reduction. These high abatement costs translate directly into lower social welfare gains, which illustrates the efficiency costs of the failure to harmonize regulations.

Scenarios 5 through 8 investigate mixed regulation under which some states adopt CATs and some states adopt rate standards. First consider Scenario 5 ("CAT Rate" in which the Coastal region adopts a harmonized CAT and the Inland region adopts a harmonized rate standard) and Scenario 7 ("Rate CAT" in which the policies are reversed).[34] The mixed regulations introduce the possibility for emissions to "leak" to the rate standard region. In Scenario 5, leakage is so severe that the carbon price in the Coastal CAT is zero, i.e., the cap is non-binding, and emissions reductions are much smaller.[35] In Scenario 7, leakage is not so severe as to result in a zero carbon price, however, emissions reductions are quite small (54 MMT) and welfare gains are eroded to $1.30 billion. Overall, average abatement costs are between 7 and 21 percent higher compared to a West-wide CAT.

Scenarios 6 and 8 illustrate policy failures across two dimensions: mixed regulation and a failure to harmonize rate standards. Not surprisingly, these scenarios

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[32] In an earlier version of this paper, our simulations did not allow for the option of building new wind capacity. In that case, compliance costs were $30 per ton of CO_2 and electricity prices were nearly $20 per MWh higher, despite less aggressive carbon reductions.

[33] Our assumption of inelastic demand also minimizes the inefficiency of the West-wide rate standard.

[34] Given that California currently has a cap-and-trade system in place, we do not believe Scenarios 7 and 8 are realistic. However, they provide the basis for understanding the complete set of incentives.

[35] Given that California currently has in place a mass-based greenhouse gas law for electricity generators and Inland states are currently unregulated, one may worry adoption of a rate standard by the Inland states would magnify leakage from the Coast to the Inland region. In unreported results, available upon request, we simulate a Coastal CAT and unregulated Inland region. Imports to the Coastal region do increase relative to our BAU scenario, however these imports from the Inland region to the Coast are smaller than under Scenarios 5 and 6. Therefore the rate standard applied to the Inland states does indeed exacerbate the problem of emissions leakage.

result in the highest average abatement costs and lowest social welfare gains of all the scenarios.

Overall, Table 1 shows substantial variation in electricity prices and carbon prices. In addition to direct effects, the electricity price variation also indicates transfers between consumers and producers. The carbon price variation indicates transfers between different types of producers with perhaps unintended consequences particularly on nuclear power.[36] To the extent that these price-induced transfers are not offset by transfers of carbon market revenue, they are a salient indicator of the effects of the different scenarios on stakeholders.

Finally, our results suggest investment in renewable energy will be an important compliance option. In an earlier version of this work (Bushnell et al. 2015), we analyze compliance without investment. Relative to those results, investment reduces the disparity between marginal compliance costs in the state-by-state scenarios, reflecting the common option of wind investment available to all states. More importantly, the addition of new investment greatly magnifies the potential leakage that could be experienced under the "uncoordinated" regulations when one region adopts a cap and another adopts a rate standard. The addition of a zero carbon investment option also greatly depresses power prices in regions adopting rate standards. This has important implications for consumers and profits for incumbent generation, particularly nuclear.

C. *Incentives to Form a West-Wide Coalition*

Our simulations suggest efficiency is enhanced when states form regional trading markets. A natural question, then, is whether states will have the incentive to join such a coalition. To address this question, we focus on outcomes if the Coastal or the Inland states either join or unilaterally depart from a West-wide coalition. The game-theoretic "normal form" is a useful way to summarize payoffs holding fixed the actions of others. Because the incentives of stakeholders within each region may not necessarily align, Table 2 presents normal forms for four main outcomes: private surplus; consumer surplus; profits; and emissions.

Private surplus—panel A of Table 2—is the sum of consumer surplus, producer surplus, and carbon market revenue and thus captures the perspective of a regional planner focused on abatement costs. Under a West-wide CAT (Scenario 1) the private surplus (i.e., abatement cost) is \$1.1 billion less than BAU. However, this panel shows that this cost is not shared equally between the two regions, but rather more is borne by the Coastal region (\$0.7 billion) than the Inland region (\$0.5 billion). This division of the burden means that the Coastal region has an incentive to deviate from a West-wide CAT. Conversely, the burden of the West-wide rate standard (Scenario 3 with cost of \$1.3 billion) is borne more heavily by the Inland region, who then have an incentive to unilaterally adopt a CAT. Thus neither a West-wide CAT nor a West-wide rate standard is a stable coalition. In fact, the only stable policy, from a private surplus perspective, is a mixed policy where the Coastal region adopts a rate

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[36] Many nuclear plants are economically marginal (Davis and Hausman 2016), and therefore vulnerable to changes in electricity prices.

Table 2—Adoption Incentives in the Coastal and Inland West

Panel A. Private surplus

		Inland	
		CAT	Rate
Coastal	CAT	−$0.68 , [✓ −$0.45]	+$0.51 , −$1.72
	Rate	[✓ −$0.20] , [✓ −$0.71]	[✓ +$0.71] , −$2.05

Panel B. Consumer surplus

		Inland	
		CAT	Rate
Coastal	CAT	−$2.93 , [✓ −$1.95]	[✓ +$2.69] , [✓ +$1.87]
	Rate	[✓ −$0.60] , −$0.79	+$2.62 , [✓ +$1.65]

Panel C. Generator profits

		Inland	
		CAT	Rate
Coastal	CAT	[✓ +$0.96] , [✓ −$2.70]	−$2.19 , −$3.59
	Rate	+$0.41 , −$3.78	[✓ −$1.91] , [✓ −$3.70]

Panel D. Emissions

		Inland	
		CAT	Rate
Coastal	CAT	−6.78 , −63.80	−13.52 , −52.31
	Rate	+12.58 , −66.10	−6.94 , −72.17

Notes: "Private surplus" is the sum of consumer surplus, generator profits (covered and uncovered), and carbon market revenue and is measured in $ billion. Private surplus in Table 1 is the sum of regional private surplus and transmission profits. The panels above exclude transmission profits. Generator profits (covered and uncovered) and consumer surplus are measured in $ billion. Emissions are measured in million metric tons (MMT). All values are measured relative to business as usual (Scenario 0). "+" indicates an increase and "−" indicates a decrease. Consumer surplus is calculated using a choke price of $100/MWh. The double circles indicate the "best response" for each region.

standard and the Inland region adopts a CAT. As we saw in Table 1, this stable policy (Scenario 7) has substantial efficiency costs.

Consumer surplus—panel B of Table 2—also casts doubt on the prospects for a West-wide coalition. Since CAT regulation results in high electricity prices, both regions would have an incentive to unilaterally deviate from a West-wide CAT. If carbon prices were fixed, Result 2 suggests that rate standards would yield the highest consumer surplus. However, when carbon prices are endogenous, the simulations show a West-wide rate standard is not a stable policy, because Coastal consumers would have an incentive to unilaterally deviate by adopting a CAT. The only stable policy from the consumer's perspective, "CAT Rate" (Scenario 5) results in substantial emissions leakage, a zero carbon price, and considerable inefficiency.

Generator profits—panel C of Table 2—is the only perspective in which West-wide coordination results in stable policies. However, this is somewhat deceptive in that generator incentives do not necessarily align. Appendix Table D13 shows that covered generators prefer rate standards and hence would have an incentive to unilaterally deviate from a West-wide CAT. Conversely, online Appendix Table D14 shows that uncovered generators prefer CAT, so would have an incentive to unilaterally deviate from a West-wide rate standard.

Emissions—panel D of Table 2—can be thought of as the environmental perspective. Alternatively, the normal form shows the considerable leakage that results

Table 3—New Capacity under Four Policy Scenarios when New Natural Gas Combined Cycle Investment Is Included and Not Included under Mass-Based Regulation

New capacity (MW)	1–CAT (mass-based)			3–rate standard			5–coast CAT and inland rate			7–coast rate and inland CAT		
	Coast	Inland	Total	Coast	Inland	Total	Coast	Inland	Total	Coast	Inland	Total
New gas gen. incl.												
Natural gas	+0	−2,017	−2,017	+0	−2,017	−2,017	+0	−2,017	−2,017	+2,196	−2,017	+179
Wind	+0	+14,550	+14,550	+1,355	+15,979	+17,334	+0	+17,130	+17,130	+4,136	+4,663	+8,799
New gas gen. excl.												
Natural gas	+5,045	+2,093	+7,138	+0	−2,017	−2,017	+0	−2,017	−2,017	+1,622	−982	+640
Wind	+0	+4,536	+4,536	+1,355	+15,979	+17,334	+0	+17,113	+17,113	+4,138	+5,419	+9,556

Notes: Results are reported as changes relative to new capacity built under business as usual, which has 2,017 MW of gas and 875 MW of wind. "+" indicates an increase and "−" indicates a decrease. Scenarios assume 10 percent load growth from 2006 levels. "New gas gen. incl./excl." means new natural gas capacity is included or excluded under the CAT. New natural gas capacity is always excluded under the rate standard. New wind capacity is included under the rate standard and can be included or excluded under the CAT because it has zero emissions.

under mixed regulation. With a West-wide CAT, total emissions fall by 7 MMT in the Coastal region and by 64 MMT inland. However, if the Coastal region unilaterally switches to a rate standard, their emissions increase by over 19 MMT. Since Inland emissions would remain capped, this increase in emissions is not offset, and aggregate emissions increase substantially. Leakage similarly results in a substantial increase in aggregate emissions (5 MMT) for the mixed regulation where the Inland region unilaterally adopts the rate standard (Scenario 5). This illustrates the leakage that results when a West-wide coalition fails to form.

D. *Entry Incentives*

The treatment of newly constructed fossil power plants in state compliance plans affects adoption incentives and efficiency. Technically, Section 111d of the Clean Air Act covers only existing sources. New sources are regulated separately and will have to comply with a source-specific CO_2 emissions rate standard. Therefore, new natural gas capacity can safely be excluded from rate standard regulation under the CPP.[37] However if states adopt CAT regulation, excluding new fossil fuel generation may create substantial scope for leakage. Because of this concern, the EPA is encouraging states who opt for CAT regulations to implement measures to limit leakage to new fossil fuel generation.

Table 3 analyzes investment in combined-cycle natural gas and wind capacity under different regulatory policies toward new generation. The first row breaks out the new capacity results in Table 1 for Scenarios 1, 3, 5, and 7 by region. When new generation is included in the state compliance plans (as our main results assume), there is substantial investment in wind capacity (9,000 to 17,000 MWs mostly Inland), but virtually no investment in natural gas (the 2,017 MW of natural gas that would have been constructed Inland in BAU is not constructed).

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[37] All rate standard scenarios exclude new natural gas capacity from the rate standard, consistent with the EPA's belief that leakage concerns are minimal under rate-based regulation.

Table 3 shows that if new natural gas is excluded from a West-wide CAT regulation, over 9,000 MW of additional natural gas capacity is constructed, much of it occurring in the Coastal region. This additional natural gas capacity comes at the expense of wind capacity, which is 10,000 MW lower. This huge, inefficient investment in natural gas capacity (over 10 percent of total capacity) illustrates the importance of including new capacity in a CAT regulation. In fact, we estimate that excluding new capacity leads to approximately 9 percent more emissions relative to CAT where new capacity is included.

By assumption, excluding new capacity has no effect on the West-wide rate standard, but it can have substantial effects on mixed regulation. Excluding new capacity from the CPP has essentially no effect when there is a Coastal CAT and Inland rate standard (Scenario 5), but this is because the CAT carbon price is zero in this scenario. In Scenario 7 (Coastal Rate and Inland CAT), excluding the new capacity results in substantial shifts in the location of the new natural gas capacity: about 1,000 MW is constructed in the Inland CAT region but not in the Coastal region. However, overall investment is largely unaffected by the decisions to include or exclude new capacity from the CAT regulation. Thus the inefficiencies of mixed regulation seem to outweigh the leakage inefficiency from excluding new capacity under the CAT regulation. However, excluding new capacity from CAT regulation could substantially change investment patterns and potentially undermine the environmental effectiveness of the policy, especially the West-wide CAT.

E. *Comparing the Proposed and Final Rules*

In June 2014, the EPA released the proposed Clean Power Plan and in August 2015 the final version was released. There are several dimensions across which the proposed and final rules differ. Some of the changes, e.g., prohibiting trading across CAT and rate states, are primarily clarifications and are outside of the scope of our analysis. However, two important changes are relevant to our analysis. First, the EPA revised the calculation of the "best system of emission reduction" used to calculate emissions reductions required under the plan.[38] The final target calculations generally relax both the CAT and rate standard. Second, the final rule also includes "new source complements" which are intended to encourage states to adopt CAT and to include new natural gas capacity in the CAT regulation. New source complements further relax the CAT but have no effect on the rate standard.

We explore the effects of these changes in Table 4. To see the effect of the final target calculations, compare the rate standard outcomes under the proposed and final rules. Despite relaxing the targets, electricity prices, rate permit prices, and emissions reductions are all essentially the same. To see the effect of the new source complements, compare CAT outcomes under the proposed and final rules. If new natural gas capacity is included, emissions reductions are approximately 12 MMT

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[38] As noted previously, the final rule eliminates energy efficiency as a fourth building block in the best system for emissions reduction. In response to stakeholder comments, the final rule changed several assumptions used to estimate the emissions reductions from heat rate improvement, re-dispatch, and increased generation from renewables. The final rule also modified the calculation of state-specific emissions reduction targets.

TABLE 4—EQUILIBRIUM OUTCOMES FOR THE FINAL AND PROPOSED RULES WITH AND WITHOUT REGULATION OF NEW GENERATION UNDER CAT

	Proposed rule						Final rule				
	New gas gen. incl.			New gas gen. excl.			New gas gen. incl.		New gas gen. excl.		
	No reg.	CAT	CATs	CAT	CATs	Rate	CAT	CATs	CAT	CATs	Rate
Electricity price ($/MWh)	$41.83	$48.27	$47.60	$43.81	$43.44	$36.44	$48.03	$47.41	$43.83	$43.48	$36.44
Electricity quantity (GWh)	787,472	−4,332	−4,079	−1,422	−1,406	+3,779	−4,178	−3,955	−1,424	−1,403	+3,780
New natural gas gen. cap. (MW)	2,017	−2,017	−530	+7,210	+7,439	−2,017	−2,017	−139	+7,138	+5,549	−2,017
New wind gen. cap. (MW)	875	+16,218	+16,413	+4,698	+3,741	+17,588	+14,550	+10,141	+4,536	+5,310	+17,334
Emissions (MMT)	330.79	−82.50	−82.50	−47.90	−52.55	−80.44	−70.58	−70.58	−46.87	−59.40	−79.11
CAT permit price ($/MT)		$22.23	$21.65	$19.50	$15.52		$21.07	$19.83	$19.43	$14.58	
Rate permit price ($/MT)						$21.99					$21.86
Consumer surplus ($ bn.)	$44.41	−$5.04	−$4.52	−$1.41	−$1.17	+$4.27	−$4.88	−$4.37	−$1.42	−$1.19	+$4.27
Covered generator profits ($ bn.)	$7.12	−$3.98	−$4.38	−$5.77	−$5.44	−$3.82	−$3.79	−$4.24	−$5.74	−$5.18	−$3.79
Uncovered generator profits ($ bn.)	$13.90	+$2.13	+$1.94	+$0.62	+$0.57	−$1.81	+$2.06	+$1.89	+$0.62	+$0.57	−$1.81
Transmission profits ($ bn.)	$0.18	+$0.00	−$0.02	−$0.09	−$0.10	−$0.01	+$0.02	−$0.03	−$0.09	−$0.10	−$0.00
Generation costs ($ bn.)	$11.91	+$1.18	+$1.45	+$1.09	+$1.34	+$1.51	+$0.92	+$1.16	+$1.07	+$1.35	+$1.48
Carbon market rev. ($ bn.)		+$5.52	+$5.36	+$5.52	+$4.77		+$5.48	+$5.43	+$5.52	+$4.52	
Abatement cost ($ bn.)		−$1.37	−$1.61	−$1.13	−$1.37	−$1.37	−$1.11	−$1.32	−$1.11	−$1.38	−$1.34
Avg. abatement cost ($/MT)		+$16.55	+$19.56	+$23.66	+$26.16	+$17.01	+$15.69	+$18.74	+$23.64	+$23.23	+$16.93
Carbon damages ($ bn.)	$14.22	−$3.55	−$3.55	−$2.06	−$2.26	−$3.46	−$3.04	−$3.04	−$2.02	−$2.55	−$3.40
Social welfare ($ bn.)	$51.39	+$2.18	+$1.93	+$0.93	+$0.89	+$2.09	+$1.93	+$1.71	+$0.91	+$1.17	+$2.06

Notes: Results from policy scenarios are reported as changes relative to no regulation. "+" indicates an increase and "−" indicates a decrease. "Abatement cost" is the sum of consumer surplus, profits (covered, uncovered, and transmission), and carbon market revenue. Consumer surplus is calculated using a choke price of $100/MWh. Carbon damages assume a social cost of carbon equal to $43. "Proposed rule" uses emissions targets comparable to the proposed rule. "Final rule" uses emissions targets comparable to the final rule in which targets are adjusted for new source complements if new natural gas capacity is included in the CAT. "New gas gen. incl./excl." means new natural gas capacity is included or excluded under the CAT. New natural gas capacity is always excluded under the rate standard. New wind capacity is included under the rate standard and can be included or excluded under the CAT because it has zero emissions.

less (4 percent of 331 MMT) under the final rule because of the new source complements. Electricity prices are similar but permit prices are slightly lower under the final rule. If new natural gas capacity is excluded, there are no new source complements and effects are complicated by different amounts of leakage.

Whether the EPA's use of new source complements could encourage CAT adoption and mitigate leakage likely depends on how covered and uncovered generators are impacted. Under the proposed rule, covered and uncovered generators would each lose approximately $1.5 billion if new generation is excluded. Thus they might be relied upon to support including new generation in the CAT. However, under the proposed rule, covered generators would prefer rate regulation to CAT. The final rule, with the new source complements, ensures covered generators are indifferent between the CAT with new gas generation included and a rate standard. In addition, the final rule further increases covered generators' profits, by about $160 million, relative to when new gas capacity is excluded. Uncovered generators always prefer CAT when emissions from new generation are included to either rate standards of CAT when new sources are excluded. These effects should reduce covered generators' resistance to adopting CAT regulation and could make both covered and uncovered generators advocates for including new gas generation. Of course, whether or not the final rule is more successful than the proposed rule at encouraging adoption of efficient regulation and limiting leakage depends on the responsiveness to these relatively minor changes.

V. Conclusion

There are many contexts in which environmental regulation and trade can interact to undermine the efficiency of both. The EPA's Clean Power Plan is a clear and timely example of these interactions. The CPP proposes major reductions in carbon emissions from generators of electricity, a good that is perfectly substitutable across neighboring states. The CPP establishes state-level targets for carbon emissions rates in lbs of carbon dioxide per megawatt hour of electricity generated. States have a great deal of flexibility in how to achieve these goals. Because this flexibility creates different incentives, effects on consumers and producers within a state could be quite different depending on the type of regulation adopted both in that particular state as well as in other states because electricity is traded regionally across state lines. Furthermore, the states' private incentives may be at odds with those of a social planner.

In this paper we have focused on the two likely market-based regulatory approaches that could be adopted by states, a mass-based (CAT) approach, and a rate standard. Our theoretical findings imply that efficiency is most likely achieved under CAT, and that a mix of CAT and rate standards is likely to create an inefficient "ordering" of generation resources. Further, we find that, while consumers in each state may prefer to coordinate on rate standards, producers can prefer to coordinate on inconsistent regulations, where different states adopt different approaches.

We investigate the importance of our theoretical findings using numerical simulations of the electricity market in the western United States. We find lack of coordination, when states independently pursue their own emissions targets without regard to electricity trading partners, leads to large inefficiencies. For example under state-specific caps, average abatement costs are 19 percent higher than under a West-wide CAT. Under state-specific rate standards, average abatement costs are 10 percent higher relative to a West-wide rate standard. Regional cooperation may not mitigate these concerns. When two regions of the West coordinate internally, but adopt different instruments, average abatement costs are between 7 and 22 percent higher than costs under a West-wide CAT. While generator incentives favor coordination, this may or may not lead to adoption of a West-wide CAT.

One unresolved aspect of the CPP is whether new natural gas generation is included under compliance plans when states adopt mass-based regulations. We examine the implications of the CPP on the construction of new natural gas and wind generation under a medium-term outlook where demand grows by 10 percent relative to 2007 levels. Whether new plants are covered under the CPP can dramatically change where new plants are built. When new plants are excluded from CPP compliance, new gas plants are built in place of new wind generation. Under mixed regulation, including new plants can shift new generation out of CAT regions toward rate regions.

Overall, our findings indicate that despite the *opportunities* the CPP provides for states to coordinate and implement compliance plans that can efficiently achieve their joint targets, the incentives of individual states to participate in those plans are conflicted. Indeed, there can easily be circumstances when states find it in their own interest to adopt a regulatory approach that is contrary to those of its neighbors.

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