When a National Cap-and-Trade Policy with a Carve-out Provision May Be Preferable to a National CO_2 Tax

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ABSTRACT

We analyze the effect of various combinations of state and national emissions policies on national emissions of a global pollutant, specifically, greenhouse gas emissions. We highlight the effect of unintended increases in out-of-state emissions on the efficacy of overlapping state policies. We show that emission taxes do not necessarily prevent a completely offsetting increase in out-of-state emissions when states add a state-level emissions tax to the national emissions tax. In particular, states small relative to their market will be unable to reduce national emissions with a state-level CO_2 tax or a system of tradable permits. However, under a national cap-and-trade regime that allows states to be carved out, a state of any size can reduce national emissions by setting a tighter state cap. This combination yields a lower total cost than the equivalent combination of national and state CO_2 taxes (if one exists) but increases the cost to consumers outside the market.

Keywords: Electricity, Tax, Tradable permits, Nested regulations, Renewable energy, Emissions, Climate change

1. INTRODUCTION

Greenhouse gas (GHG) emissions are widely regarded as a textbook case of a global externality warranting coordinated global action (Oates, 2001). However, what appears to be emerging from international negotiations is a weaker agreement whereby countries set their own targets for emission reduction (Diringer, 2013). One impediment to a stronger global commitment is the lack of national consensus within some large industrialized countries including the United States and Canada (Rabe et al., 2005; Bulkeley, 2010). In such countries (and elsewhere too), lower levels of government are undertaking various measures to reduce GHG emissions (Rabe, 2008). The range of policy measures includes carbon dioxide (CO_2) taxes (e.g., the province of British Columbia in Canada and the city of Boulder, Colorado in the U.S.), tradable emission permits, henceforth referred to as cap-and-trade, (e.g., the state of California and the Regional Greenhouse Gas Initiative by states in the north-eastern U.S.), emission intensity standards (e.g., the province of Alberta in Canada and the state of California in the U.S.) and renewable energy policies (e.g., state-level Renewable Portfolio Standards, feed-in-tariffs, and various forms of subsidies).

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While economic theory suggests that emission pricing, either directly through a CO_2 tax or indirectly through a cap-and-trade program, is the cost-effective approach, renewable energy policies appear the more popular approach for state-level action. Justifications for renewable energy include the local economic benefits of "home-grown" energy resources for long-term economic development and the benefits of reducing (or even simply aiming) to reduce GHG emissions (Rabe, 2008). Bushnell et al. (2008) argue that in a market comprised of many states which are not subject to a unified climate policy and which do not have state-level CO_2 reduction programs, if one state decides to reduce its own emissions, then this goal may be achieved by simply reshuffling pollution within the market such that the state with the policy consumes "cleaner" products while the rest of the market consumes the "dirtier" products. For instance, electricity is susceptible to reshuffling because wholesale purchases of electricity are financial arrangements which are not tied to the physical exchange of electrons. Thus, if "clean" products already have a significant market share, the policy can be satisfied with no change in production or emissions. Indeed, in many electricity markets in the U.S., sizeable zero-carbon electricity generating capacity in the form of nuclear and hydroelectric power exists which may prevent policies targeting CO_2 emissions from being effective in many states.

The goal of this paper is to formally model the interaction of policies at multiple levels of jurisdiction, specifically at the federal and state level, in order to identify the effect on pollution and the relative costs and benefits of CO_2 taxes vis-a-vis cap-and-trade at the federal level when combined with overlapping state-level climate policies (specifically, CO_2 taxes[1] or renewable portfolio standards (RPS)).[2] This research is motivated by the premise that in countries where national opinion on climate change is divided, in the near to medium-term, any national agreement, should it be achieved, would likely be viewed by some states as insufficiently stringent and such states would likely pursue overlapping state-level policies. While an emission tax and a cap-and-trade program are *ex ante* equivalent (Jaffe et al., 2003), we show that when states enact additional emission control policies, the two national policies could yield different results. In any case, the cost of a given reduction in national emissions is always lower under a unified national emissions policy than under differentiated and/or overlapping policies by multiple jurisdictions.

Several authors have analyzed the effect of combining state and federal emissions reduction policies (Bushnell et al., 2008; McGuinness and Ellerman, 2008; Burtraw and Shobe, 2009; Goulder and Stavins, 2011a,b; Williams, 2012). One common conclusion in these studies is that under a national cap-and-trade regime, additional state policies have little to no effect on national emissions as any additional emission reduction at the state or local-level, beyond that which would have resulted under the national policy alone, only allows emissions from the rest of the nation to rise back to the level of the national cap. However, by developing innovative policies and infrastructure, state and local regulators could help lower the cost of achieving national emission goals (Burtraw and Shobe, 2009). Another set of papers analyzes the effect of renewable energy policies operating under the European Union (EU) Emissions Trading System (ETS). See Fischer and Preonas (2010) for a summary of this literature. These articles conclude that overlapping national renewable energy policies raise the cost of national cap-and-trade policies without affecting national emissions and may benefit the dirtiest fuels.

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1. At the level of lower jurisdiction, CO_2 taxes and cap-and-trade are equivalent but we will show that these two policies exhibit some differences at the level of the higher jurisdiction

2. For a detailed discussion of the motivation for state-level policies for addressing climate change we refer to Rabe (2008).

The offsetting increase in consumption outside the state under a national cap could, however, be avoided by either "carving-out", i.e. exempting states from the national policy provided they set a stricter state policy, or through price-based regulations, e.g. a CO_2 tax (Goulder and Stavins, 2011a).[3] Contrary to Goulder and Stavins (2011a), we show that a price-based regulation, specifically a CO_2 tax, does not necessarily prevent a completely offsetting increase in emissions elsewhere when states adopt an additional CO_2 tax on top of the national CO_2 tax. Consequently, we also show that, for small states (relative to their market, see Section 2.3 for definition) that are subject to a national CO_2 tax, a state-level renewable energy policy is able to further reduce national emissions while a state-level emissions policy cannot. However, if a carve-out provision is added to a national cap-and-trade program, allowing states to exempt themselves from the national policy provided they set a tighter cap, and a state decides to set a tighter cap, emissions must decline regardless of the size of the state as the sum of permitted national and state emissions is now lower. Furthermore, because any reshuffling[4] or leakage[5] of emissions within the market caused by a tighter state cap would increase the national emissions permit price (in order to keep emissions outside the state constant), a cap-and-trade policy with a carve-out provision limits reshuffling and leakage within the market and reduces the cost of achieving a given reduction in emissions with a state policy relative to the cost under a national CO_2 tax coupled with an additional state CO_2 tax. However, a tighter state cap under a national cap-and-trade policy with a carve-out raises electricity costs for consumers outside the market relative to the costs before the tighter state cap was implemented and relative to those under equivalent national and state CO_2 taxes, which may impede support for state carve-outs from the national regime.

Our findings result from the following key features of our model: (i) the commodity (or commodities) under consideration can be produced with inputs (say, energy) from different sources or using different technologies resulting in different emissions per unit of output and at least one such input or process results in a zero emission product. In our example, the commodity is electricity derived from coal, natural gas, nuclear, hydro and renewable resources, the latter three being considered zero emission resources; (ii) the commodity is traded at negligible transportation cost within a specified geographic region that spans multiple policy jurisdictions. In our example, it refers to the free flow of electricity within a regional interconnected grid; (iii) under any state-level climate policy, retailers are accountable for emissions *attributable* to final in-state sales regardless of where emissions actually arise in the supply chain, which may be outside the policy jurisdiction. In our example, this implies that even though electricity consumption is emission-free, regulated state retailers are accountable for CO_2 emitted during generation of the electricity imported into the state.

Relaxing the above assumptions affects our findings as follows. Without a zero-carbon resource, pure reshuffling of output would not be sufficient to avoid the state CO_2 tax and thus a state CO_2 tax would be effective even for small states. As the cost of reshuffling increases, the ability of state-level policies to affect national emissions increases for any given state size. Thus the higher the transportation costs (or any other costs associated with shuffling the distribution of the final good), the more effective state-level policies will be at reducing national emissions. The

3. As noted by Goulder and Stavins (2011a), there is ample precedent for carve-out provisions in the context of fuel economy and emissions standards. However, we are not aware of any carve-out provisions associated with cap-and-trade policies.

4. Defined here as the reallocation of existing emissions across jurisdictions.

5. Defined here as an increase in emissions outside the state caused by an increase in consumption of carbon-intensive resources outside the state due to the reduction in demand for carbon-intensive resources within the state.

Figure 1: The Model
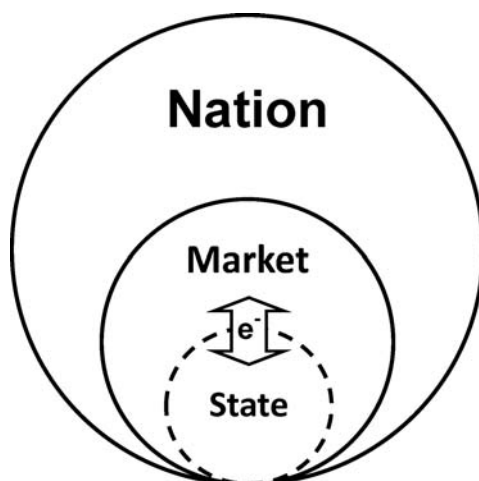
implications of state policies directed at targets other than the emissions attributable to final in-state sales, say, extraction of primary fossils fuels, are discussed in Section 3.5.

While our mathematical and numerical illustrations are for a single commodity, specifically electricity, the simplified model allows for more general conclusions about emission policies spanning multiple economic activities. As the scope of the policy at either the state-level, the national-level or both widens to include emissions from multiple sectors, so does the scope for reshuffling and leakage, causing the efficacy of state-level emissions policies to depend on how the size of the state changes relative to the broader market(s) across which resources can be reshuffled. The comparisons of the various state and national policy combinations are, however, unaffected. Given the global effects of CO_2 emissions, our results also speak to the interactions that occur when global policies overlap national policies or state policies overlap local policies and product markets are larger than the smaller jurisdiction. Finally, although we focus on only three policies - CO_2 taxes, cap-and-trade programs, and RPS, our framework can be extended to consider many other policies such as emission intensity standards, subsidies for renewable energy and border adjustment policies.

2. MODEL

To demonstrate how national and state climate policies might interact, we construct a model comprised of three regions: the nation, a regional market embedded within the nation, and a state comprising a portion of the regional market. A market should be interpreted as an integrated wholesale market in which electricity can flow freely within the market and in which a centralized body clears wholesale transactions and manages power flows. A national policy applies to all regions unless it has a carve-out provision and the state has enacted a sufficiently stringent state-level policy, in which case the state follows its own policy while the rest of the nation is subject to the national policy. We later discuss how policies in the rest of the market (outside the state) might affect our results.

We analyze the interaction of different state and national policy regimes in a static partial equilibrium framework assuming perfect competition. As illustrated in Figure 1, power can flow freely between the state and market, but does not flow into or out of the market. We assume there

are four types of fuels available to generate electricity: coal, natural gas, qualifying renewable, and non-qualifying zero-carbon. Qualifying renewable fuels represent those that would qualify as renewable under existing RPS policies. Non-qualifying zero-carbon fuels represent nuclear and large hydroelectric facilities, which do not generally qualify as renewable under current state RPS policies. Given the significant environmental and regulatory hurdles to building new nuclear or large hydro generation capacity in addition to their high capital cost (CBO, 2011), we assume that the capacity of non-qualifying zero-carbon resources is fixed. There is one firm operating each generation technology which converts the input (fuel) into output (electricity) and emissions in fixed proportions.

Within the market, the firm may sell power either to the state or to the rest of the market at the electricity price in that region but may be required to pay an explicit or implicit tax or may receive an implicit subsidy based upon the policy (policies) in place in the region(s) to which it sells (not based upon the location of the producer). Electricity sold outside the market is produced separately from the in-market electricity and is therefore subject to a separate supply curve.

2.1 Mathematical Formulation of the Model

Let p denote price, q denote quantity of electricity, and the subscripts c, g, r, and z denote coal, gas, qualifying renewables, and non-qualifying zero-carbon resources respectively. A representative consumer in each region, r, maximizes a quasi–linear utility function, $u^R(q^R) - p^R q^R$.[6] $u^R(\cdot)$ is the consumer's utility of consuming electricity in region r. A state comprises a fraction ρ of the market and therefore consumes ρ of the electricity pre-policy, which will be reflected in the preferences of the representative consumers.

Each producer seeks to maximize profit, which is defined as the sum of the revenue from electricity sold in each region less the cost of generating the electricity:

$$\max_{q_f^s, q_f^m, q_f^n} \quad (p^s + x_f^s + x_f^N)q_f^s + (p^m + x_f^N)q_f^m - c_f^M(q_f^s + q_f^m) + (p^n + x_f^N)q_f^n - c_f^n(q_f^n) \tag{1}$$

$$\text{s.t.} \quad q_f^s \geq 0, q_f^m \geq 0, q_f^n \geq 0 \tag{2}$$

f indicates the fuel utilized by the producer. s indicates the state, m indicates the rest of the market, M indicates the market as a whole, n indicates the rest of the nation (outside the market), and N indicates the nation as a whole. Market clearing conditions ensure that the sum of production from each fuel for each region equals total consumption in each region ($q_c^R + q_g^R + q_r^R + q_z^R = q^R$).

$p^s + x_f^s + x_f^N$ is the price received by the producer in the state for the electricity sold, q_f^s. p^s represents the price of electricity in the state, x_f^s and x_f^N represent the explicit or implicit tax or subsidy per MWh of electricity produced by each fuel f from the state policy and national policy respectively. The values of x_f^s and x_f^N under each policy are discussed in Section 2.2. Similarly, $p^m + x_f^N$ is the price received by the producer in the rest of the market and $p^n + x_f^N$ is the price received by the producer in the rest of the nation.

$c_f^M(\cdot)$ and $c_f^n(\cdot)$ represent the cost of generating electricity from each fuel, f, in the market and the rest of the nation respectively. The assumption of separate cost curves for the market and the rest of the nation ensures that supply to one market does not affect supply in another market.[7]

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6. With this utility function, we implicitly assume that the cost of emissions to a consumer is additively separable from the consumer's utility of electricity and money.

7. Even when technical or economic factors limit the exchange of a commodity (say electricity or biofuel) to a specified geographic region, the intermediate inputs used to produce the commodity (such as coal or crops) need not face such

Non-qualifying zero-carbon generation is assumed to have zero marginal cost but to face a capacity constraint such that $q_z^s + q_z^m \leq Q_z^M$ where Q_z^M is the total existing capacity of non-qualifying zero-carbon generation in the market. In the rest of the nation, non-qualifying zero-carbon generation is fixed at Q_z^n.

2.2 Mathematical Formulation of Each Policy

2.2.1 Renewable Portfolio Standard

An RPS dictates that qualifying renewable generation must be a specified share of total generation, α. The RPS requirement is represented by:

$$\frac{q_r}{q_c + q_g + q_z + q_r} \geq \alpha \quad \text{or} \quad q_r \geq A(q_c + q_g + q_z) \text{ where } A = \frac{\alpha}{1-\alpha} \qquad (3)$$

Under an RPS, suppliers of electricity must demonstrate that at least α percent of the electricity sold to end-users was generated from qualifying renewable resources. To do this they can either generate electricity using renewable resources or purchase renewable energy credits (RECs) at price γ from other producers generating electricity using renewables. Thus, a supplier of electricity from renewable resources receives an implicit subsidy γ, while a supplier of electricity from conventional resources pays an implicit tax $A\gamma$ for electricity sold in region(s) with an RPS.

2.2.2 Tradable pollution permits or Cap-and-Trade

A cap-and-trade program specifies a maximum level of CO_2 emissions by giving away or auctioning a number of permits equal to the cap. The cap-and-trade requirement is represented by:

$$e_c q_c + e_g q_g \leq \bar{E} \qquad (4)$$

We assume that each producer must purchase one carbon credit per of emissions at price τ for electricity sold in the region(s) with cap(s). The price is set by competition for the limited supply of credits.[8] e_c and e_g are the tonnes of CO_2 emissions per MWh of electricity generated by coal and natural gas.

2.2.3 CO_2 Tax

With a CO_2 tax, the regulator selects a tax of \$$T$/tonne of CO_2 emissions to achieve a given emissions reduction. Producers using coal to generate electricity, which emits e_c tonnes of CO_2 per MWh, pay $e_c T$\$/MWh of generation, and producers using natural gas pay $e_g T$\$/MWh for electricity sold in region(s) with a CO_2 tax.

constraints, in which case, the cost function, and therefore the supply, in one market will be related to that in the other. For instance, a reduction in demand for the input in one market, increases the supply of inputs to the other market. This is yet another mechanism of leakage, one that manifests via input markets as opposed to the output market which is the focus of our illustration and does not weaken our findings.

8. Whether credits are distributed for free or auctioned, the price of a carbon credit will end up the same though firms' profits will differ based upon the number of credits granted for free.

2.2.4 Carve-Out Provision

To implement the carve-out provision, we assume that a state's pre-state-policy share of emissions is equal to its pre-state-policy share of consumption. For example, prior to the state policy, the national cap on emissions is 1,000 tonnes. If the market emits 100 tonnes and the state is 25 percent of the market, then the state is assumed to emit 25 tonnes of CO_2 pre-state-policy and the national cap with the state carved out of the policy would be set to 975 tonnes and the state's cap must be less than or equal to 25 tonnes.

2.3 A Classification of States Based on Their Market Share

A state's ability to affect national emissions using a state policy is determined largely by its size, measured in terms of its share of consumption (or emissions). We classify a state as small if its total consumption is less than the quantity of zero-carbon resources in the market. To understand the typical size of states relative to their markets in the U.S., we examine data on electricity consumption and fuel mix for each state relative to its relevant wholesale market.

In the U.S. there are seven wholesale electricity markets: Independent System Operator New England (ISO-NE), the New York ISO, the Pennsylvania Jersey Maryland (PJM) Interconnection, covering much of the Mid-Atlantic and Midwest, the Midwest ISO (MISO), the Electric Reliability Council of Texas (ERCOT), the Southwest Power Pool (SPP) (as of January 2014) and the California ISO. As our results pertain mainly to states participating in a wholesale market with other states, we exclude those states that do not participate in a wholesale market as well as Texas, for which the bulk of the electricity grid is isolated from the rest of the U.S.[9] We also exclude California and New York as these states operate their own wholesale markets but trade extensively with neighboring regions, making it difficult to acquire the statistics needed for our analysis. After these exclusions, there are 34 states in the U.S. in which at least some utilities participate in a larger wholesale market (ISO-NE, PJM, MISO, or SPP).

We obtained data on state-level electricity consumption from the EIA's Electric Sales, Revenue, and Average Price Report for 2011[10] while data for market-level fuel mix was obtained from the website for each wholesale electricity market. The data indicate that of the 34 states that participate in a larger wholesale market, only eight could be considered large. Of these eight, four are located in MISO, which had only 12.8 percent of generation from zero-carbon resources in 2011. Three are located in SPP which receives only 14 percent of its power from zero-carbon resources in 2012.[11] The remaining large state in 2011 was Massachusetts, which made up 50.5 percent of ISO-NE in terms of consumption, while ISO-NE had 41.3 percent of generation from zero-carbon resources. In PJM, the largest state by consumption is Virginia with 25.3 percent of consumption, but generation from zero-carbon resources in 2011 was 35 percent. Therefore no state in PJM could be considered large in 2011. Consequently, the majority of states that participate in larger markets should be considered small.[12]

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9. For states that do not trade with other states, a national cap-and-trade with a carve-out provision and a national CO_2 tax will lead to the same outcome if states set more stringent emissions policies as will be discussed below.

10. See http://www.eia.gov/electricity/data.cfm#sales for state-level data

11. 2012 is the only year for which data was available.

12. This analysis excludes each market's import capability, but if it were included in the analysis, the share of zero-carbon resources deliverable into the market would increase while the relative size of the state would diminish, rendering states even more likely to be small by our definition.

196 / *The Energy Journal*

3. RESULTS AND DISCUSSION

3.1 National CO$_2$ Tax or No National Policy

3.1.1 Small States

When there is either a national CO$_2$ tax or no national climate policy and other states in the market do not have climate policies, a state-level CO$_2$ tax will be unable to reduce national emissions if the state is small (i.e., the state's pre-policy consumption is less than the quantity of zero-carbon generation already present in the market).[13] This occurs because when the state is small, there are sufficient zero-carbon resources already existing in the market for state consumers to trade all generation from fossil fuels for generation from zero-carbon fuels with no net change in production, emissions, or tax burden. This reallocation of existing production across consumers is what we henceforth refer to as reshuffling.

To illustrate this result more clearly, suppose there are two fuels, zero-carbon and coal. Pre-state-policy all producers using coal pay a national CO$_2$ tax of $\$T^n$/tonne of CO$_2$ while producers using zero-carbon resources pay no CO$_2$ taxes. After the state adds a CO$_2$ tax of $\$T^s$/tonne of CO$_2$ on emissions from generation sold in-state, suppose total production does not change but producers sell only generation from zero-carbon resources to in-state consumers to avoid paying the state tax. Since we have assumed that the state is small, there are sufficient zero-carbon resources to serve all in-state demand and so consumption in-state need not change. Any excess zero-carbon generation and all coal generation is sold to out-of-state customers. Since total production did not change, total production less in-state zero-carbon generation is equal to the rest of the market's pre-state policy consumption, meaning that the rest of the market's consumption does not change post-state-policy. Finally, since all coal generation is sold in the rest of the market, generators using coal still pay $\$T^n$/tonne of CO$_2$. With production, consumption, and total tax paid unchanged, the price of electricity will not change either and so there is no reason to change production or consumption. Note that this result requires only that trade between states is possible, that reshuffling costs are negligible, and that zero-carbon resources already exist and are available to shuffle. As the cost of reshuffling increases, the ability of state-level policies to affect national emissions increases for any given relative state size.

When some of the pre-existing zero-carbon fuels would qualify as renewables under a state RPS while others would not, a small state may be able to achieve emissions reduction under a state RPS even though a state CO$_2$ tax would be ineffective.[14] This is because an RPS policy requires a more specific type of zero-carbon resource meaning that there are, by definition, fewer qualifying resources already present in the market to reshuffle. As a result, even for a small state, a real change in production will be necessary to meet a sufficiently stringent RPS policy and emissions within the market will decline. Therefore, since emissions outside the market are not affected by the state's RPS policy and emissions in the market fall, the state RPS policy will reduce emissions in the nation as a whole. See Appendix A for the mathematical proof.

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13. We assume that in formulating their emissions policies, states are primarily concerned with their effect on national emissions as off-setting increases out-of-state from a global pollutant reduce the benefit of the state policy.

14. If a state is so small that the pre-state-policy consumption in-state is less than pre-existing generation from qualifying renewable fuels, a state RPS policy will also be ineffective.

Considering that about two-thirds of the states in the U.S. participate in larger markets, and that among those states, the majority can be considered small relative to their market, our results suggest that should such a state decide to adopt unilateral measures to reduce CO_2 emissions, an RPS approach is more likely to allow them to have an impact on national emissions either in the absence of national policy or in the presence of a national CO_2 tax. This is one possible rationale for the current U.S. climate policy landscape, in which there is no national climate policy and 29 states have adopted RPS policies.[15]

3.1.2 Large States

Now consider the case of a large state: because existing zero carbon resources cannot satisfy its full demand, some producers will have to pay the state CO_2 tax in addition to any national CO_2 tax, which increases their tax burden. The increase in tax burden caused by the state's CO_2 tax will therefore generally cause a reduction in national emissions. However, if there are fuels that are zero-carbon but do not qualify as renewables under an RPS, large states will be able to achieve larger national emissions reductions with a state RPS than with a state CO_2 tax, provided there is at least one other state in the market. See Appendix B for the mathematical proof.

Intuitively, this result follows because under the most stringent state RPS, the state would consume only qualifying renewable fuels, ceding all existing non-qualifying zero-carbon generation to the rest of the market and reducing demand for coal and natural gas in the rest of the market relative to the demand under an infinitely high state CO_2 tax, under which only coal and natural gas would be available to the rest of the market as the state would consume *all* zero-carbon resources. Therefore, total emissions under the most stringent RPS will be lower than under an infinitely high CO_2 tax. If a state does not participate in a larger market and therefore does not trade with other states, then a state CO_2 tax and a state RPS will be able to achieve the same maximum reduction in emissions. When both a state-level CO_2 tax and a state-level RPS can achieve a given reduction in emissions, intuition suggests that a state CO_2 tax will be more cost-effective than an RPS at reducing emissions as it targets emissions directly and provides more flexibility in the options for compliance. This hypothesis is confirmed by our simulation results in Section 3.3.

3.2 National Cap-and-Trade Policy with a Carve-Out Provision

We next consider the effect of a national cap-and-trade program with a carve-out provision. Recall that under a national cap-and-trade program without a carve-out provision, state policies cannot induce additional emission reductions because any reduction in emissions caused by a state policy will lower the national emissions permit price and therefore cause a corresponding increase in emissions outside the state up to the level of the national cap. The carve-out provision allows any state to become exempt from the national cap provided that it implements a tighter state cap.[16] Therefore, if a state decides to set a tighter cap, the level of emissions outside the state does not change while emissions within the state decrease. Together this implies that, regardless of the size of the state with the tighter cap, the state cap will cause national emissions to decline.

15. Database of State Incentives for Renewables & Efficiency, http://www.dsireusa.org

16. In our model, a state CO_2 tax set above the level of the current national carbon credit price would generate the same outcome as a tighter state cap. Also, note that carving a state out of a national CO_2 tax policy provided it sets a higher tax yields the same outcome as adding a state tax on top of a national tax since the total tax would be the same.

Under a national cap-and-trade with carve-out, when other states in the market do not have climate policies, a tighter state cap pushes carbon-intensive resources out of the state, increasing emissions in the rest of the market. To compensate, emissions outside the market must decline. Unlike under a national CO_2 tax where reshuffling may have no effect on prices and the total tax burden, in this case, reshuffling of resources within the market would raise emissions in the rest of the market and force consumers outside the market to make costly reductions in emissions to meet the national cap. Thus, while a state CO_2 tax or RPS in addition to a national CO_2 tax (or no national policy) leaves consumers outside the market unaffected, a tighter state cap under a national cap-and-trade with carve-out imposes additional costs on consumers outside the market when the state with the tighter cap participates in a larger market. If the state does not participate in a larger market, then a state emissions policy would not cause reshuffling regardless of the national policy (since there is no region to reshuffle with), and therefore a state CO_2 tax that causes a reduction in emissions beyond that caused by a national CO_2 tax would lead to the same outcome as a tighter state cap and a national cap-and-trade program with a carve-out that mandated the same total reduction in emissions.

3.3 Comparison of Costs under Various Policy Combinations

Under a national CO_2 tax, if a state policy is enacted that is sufficiently stringent to cause national CO_2 emissions to decline and that state also participates in a larger market with other states that do not have climate policies, then resources in the market will be reshuffled and the price paid to carbon-intensive resources must fall to reduce generation from carbon-intensive resources and thereby reduce CO_2 emissions. If the price of carbon-intensive resources falls, then consumption of carbon-intensive resources in the rest of the market will rise, the phenomenon known as leakage. Consequently, for a state to reduce national emissions by X tonnes it will have to reduce its own emissions by more than X tonnes to account for the increase in emissions outside the market. However, a national cap-and-trade policy with a carve-out provision limits both reshuffling and leakage within the market because any increase in emissions in the rest of the market forces consumers outside the market to make costly reductions in emissions to ensure the national cap is met, which increases the national emissions permit price and prevents large consumption increases in the rest of the market. Thus, a reduction in emissions caused by altering consumption within the state by a given amount is met by a smaller increase in emissions in the rest of the market than if a national CO_2 tax were in place and therefore, the net emissions reduction is larger for a given change in state consumption patterns. As a result, the cost of a given reduction in emissions achieved by a state policy is lower under a national cap-and-trade with carve-out than under a national CO_2 tax.

To illustrate the degree of difference between the costs of the three national-state policy combinations (National CO_2 Tax + State CO_2 Tax, National CO_2 Tax + State RPS, and National Cap-and-Trade with Carve-out + State Cap) we perform numerical simulations for two relative state sizes: 25 percent of the market and 75 percent of the market. A state that is 25 percent of its market is small in our simulations as generation from zero-carbon resources was 32 percent of total consumption. A state that is 75 percent of its market is therefore large. For each simulation, we calculate the surplus accruing to the consumers in each region and the surplus accruing to each type of producer. The sum of the consumer surplus, producer surplus and the total tax or emissions permit revenue paid by each region yields the national surplus under each scenario. The reduction in national surplus due to a particular policy is the cost of the policy. Details on the data and calibration can be found in Appendix C.

Figure 2
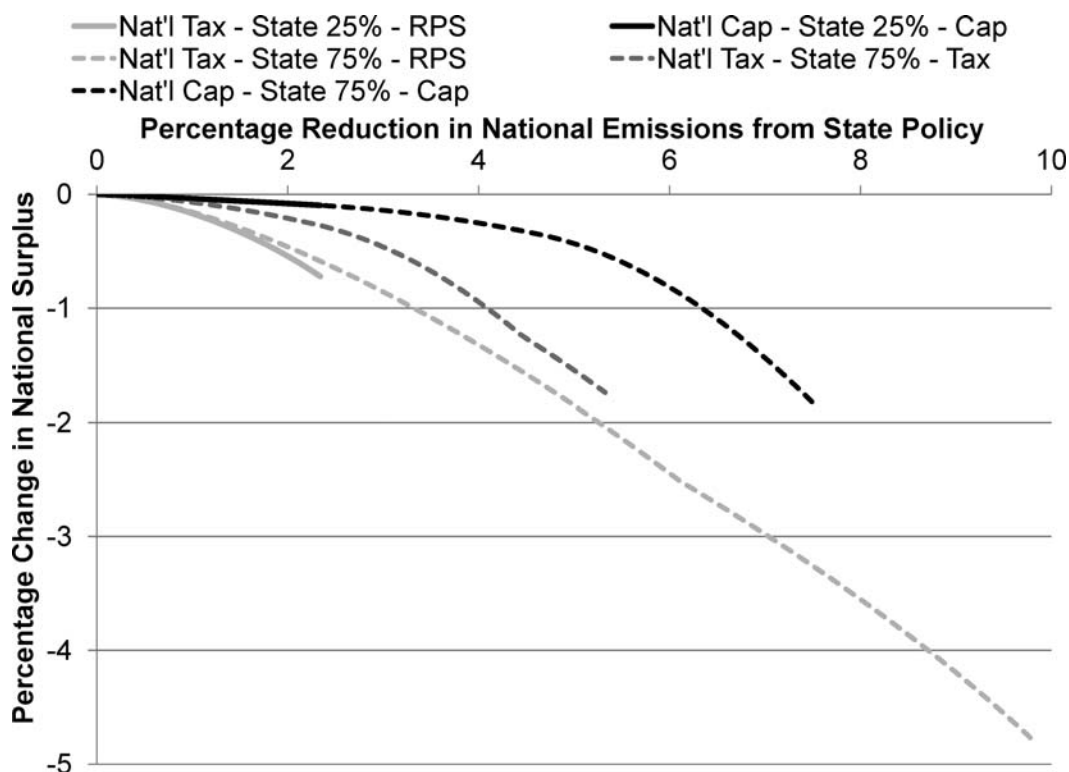
The figure depicts the relationship between national surplus changes and national emissions reductions for various combinations of national and state policies. Each line represents the relationship for a fixed national policy and a state policy gradually increasing in stringency.

Figure 2 plots the percentage change in national surplus against the percentage reduction in national emissions caused by each national-state policy combination under our baseline parameters for two relative state sizes, 25 percent and 75 percent. Note that cap-and-trade polices at both the national and state levels *without* state carve-out and national and state CO_2 taxes with a small state result in the state having no incremental impact on national emissions and are therefore not shown. In the figure, the national policy is held fixed at $20 (or at the national cap that is equivalent when there is no state policy) while the state policy increases in stringency. The lines terminate at the maximum achievable emissions reduction given the policy combination and relative state size.

The figure verifies our intuition that the cost to achieve a given reduction in CO_2 emissions using a national cap with a carve-out and tighter state cap is less than the cost using a national CO_2 tax with a state RPS or CO_2 tax. The figure also confirms that the cost of a national CO_2 tax with a state CO_2 tax is less than the cost of a national CO_2 tax with state RPS when both are feasible and that a state RPS can achieve larger reductions in emissions than a state CO_2 tax under a national CO_2 tax. The exact differences between the costs of the different policy combinations depend on the parametrization of the model, but the ordering of the policies in terms of cost-effectiveness is invariant over a broad range of elasticities of regional demand and fuel supply, region sizes and fuel mix.

In summary, when there is a national CO_2 tax or no national emissions policy and a state is small or a state is large but desires a large reduction in emissions, a state RPS may be able to

achieve the state's desired emission reduction while a state CO_2 tax would fail. For smaller emissions reductions in large states, either a state RPS policy or a state CO_2 tax will be able to reduce national emissions, though the state CO_2 tax will be more cost-effective. When there is a national cap-and-trade with a carve-out, a state of any size can cause a reduction in national emissions by setting a tighter state cap. Furthermore, the cost of a given reduction in emissions under a national cap-and-trade with a carve-out and a state cap will be lower than the cost under a national CO_2 tax with a state RPS or CO_2 tax. Thus, a national cap-and-trade policy with a carve-out provision may be preferable to a national CO_2 tax.

However, the distribution of the costs from each national policy differs. Under a national CO_2 tax, a state policy only affects the market in which the state participates and therefore only affects costs for consumers and producers inside the market. Under a national cap-and-trade with a carve-out, a state policy also increases costs for consumers and producers outside of the market. Thus, although a national cap-and-trade policy with a carve-out is less costly than a national CO_2 tax when states initiate stricter policies, a national CO_2 tax ensures that the state pays for the majority of the costs of their policy-making. In other words, a national CO_2 tax allows large states to reduce emissions if they so desire, while a national cap-and-trade program allows a state of any size to reduce national emissions, but also imposes additional costs on other states. This may cause many states to oppose carve-out provisions.

3.4 Effect of Policies by Other States Within the Market

We now consider the implications of overlapping policies in other states within the market. We build on the intuition developed in the prior sections to outline how different combinations of policies across states might interact under each of the national policies considered here.

Under a national CO_2 tax or no national policy, if at least one other state in the market has a binding RPS (targeting in-state consumption of renewables rather than in-state production), a state of any size will be able to implement an RPS policy that binds and reduces national emissions. This is because the states that already have RPS policies will be consuming all qualifying renewable resources in the market and will be unwilling to relinquish them. Therefore, to satisfy a new RPS policy in a state with no prior climate policy, production from qualifying renewable resources must increase, which will cause prices and production from all resources to adjust. Since qualifying renewable generation is increasing, generation from coal and natural gas will decrease.

To be able to affect national emissions via a state-level CO_2 tax when there is a national CO_2 tax or no national policy and other states in the market have RPS policies, a state's pre-state-policy consumption must be larger than the existing non-qualifying zero carbon resources. The size barrier a state must exceed to be able to implement an effective CO_2 tax is now lower because the other states with RPS policies will not be willing to trade qualifying renewable resources for fossil fuels with no change in prices, as this trade would increase the cost of complying with their RPS policies. However, the other states with RPS polices are willing to trade non-qualifying zero-carbon resources because these fuels pay the same implicit tax as fossil fuels under an RPS policy.

If other states have CO_2 taxes that reduce national emissions in the presence of a national CO_2 tax or no national policy, the effect of a state CO_2 tax in a new state will depend on the level of the new CO_2 tax relative to existing state CO_2 taxes in the market as well as the relative size of the state adding the new CO_2 tax. For instance, suppose there is one other state, state A, with a CO_2 tax, T^A. To be effective at reducing national emissions, state A must be large. If state B sets a new CO_2 tax, $T^B < T^A$, it will not be able to draw in any zero-carbon resources from state A because the value of zero-carbon resources is higher in state A. However, generation and emissions

will change in this case because all generation sold in state B will be carbon-intensive and subject to the tax T^B.

If state B's electricity consumption is less than the quantity of generation from zero-carbon resources prior to the initiation of state B's policy (or in other words, if state B is small), then setting T^B above T^A will generate the same emission reduction as setting T^B equal to T^A. This occurs because when $T^B \geq T^A$, zero carbon resources are at least as valuable in state B as in state A, which will cause zero-carbon resources to be shuffled to state B. When state B is small, all demand in state B can be satisfied with existing zero-carbon resources. If state B is large, then increasing state B's CO_2 tax from T^A to a higher level will generate additional reductions in emissions.

If there is a national cap-and-trade policy with a carve-out and states can be carved out of the national policy only if they set a tighter state cap, then any other type of state policy would overlap with the national cap (rather than supersede it) and would therefore be unable to affect national emissions. States may nevertheless have other types of climate policies if they believe they are correcting other externalities. In this case, the other states' policies will generally further limit the reshuffling of resources that can occur when a state carves itself out of the national cap to set a tighter cap, but they will not affect the state's ability to reduce emissions. If other states in the market are already carved-out, mathematically, total emissions must decline when an additional state is carved out since the sum of the caps is now lower.

In summary, if other states have RPS policies that are binding, then a state of any size will able to reduce emissions with an RPS policy since all qualifying renewable resources are being utilized. Under a national CO_2 tax, increasing the state CO_2 tax within one state up to the level of the maximum state CO_2 tax in the market will always bring about additional emissions reductions. Depending on the size of the state, CO_2 taxes above level of the maximum state CO_2 tax may or may not have an additional effect. Under a national cap-and-trade program with a carve-out, when other states in the market have been carved out, carving out an additional state brings about additional emissions reductions.

3.5 Vertical Targeting of State Policies

We modeled the state-level policy as targeting emissions that are attributable to in-state consumption as opposed to emissions from in-state production. Under the assumption that one motivation for unilateral state-level (national) policies targeting global public goods is a concern for the common good rather than just the economic impacts to the state (nation), it is consistent for states (nations) that are net importers of pollution (i.e., the emissions embodied in the goods imported for domestic consumption exceed that embodied in what they export) to target emissions from in-state (national) consumption. In fact, many of the states in the U.S. and several of the nations in the European Union that support strong policies to limit CO_2 emissions are net importers of energy and/or energy-intensive goods and services.

Another alternative is to tax fossil fuels directly based on their carbon content rather than taxing emissions from use of fossil fuels. Again, states could either tax producers of the fossil fuels based on their production within the state or based upon their sales in the state. For states with little production of fossil fuels, taxing in-state production would have little effect. Taxing out-of-state producers based on their sales of fossil fuels in-state would also, in effect, raise the cost of in-state production of energy intensive commodities and eventually lead to relocation of such activities, which is a type of leakage.

4. CONCLUSION

We analyze the effect of two different state-level policies—a CO_2 tax (or an equivalent cap-and-trade system) and an RPS, on national emissions of a global pollutant under different national policy regimes—no national policy, a national CO_2 tax and a national cap-and-trade program with state carve-out.[17,18] We highlight the effect of pollution shuffling and leakage on the ability of state-level policies to reduce national emissions and the cost they impose on the rest of the nation.

We find that the effectiveness of a state RPS or CO_2 tax at reducing national emissions will be influenced by a set of common factors whether there is a national CO_2 tax or no national climate policy. In both cases, a state whose consumption is less than the quantity of qualifying renewable generation within the larger market that can be reallocated to that state, will not be able to affect overall emissions with either an RPS or CO_2 tax at the state-level. A state whose consumption is greater than the existing qualifying renewable generation but less than the existing zero-carbon generation in the market (small states) can affect national emissions by adopting a state-level RPS policy, while a state-level CO_2 tax will not be able to reduce emissions due to reshuffling of zero-carbon resources. We thus show that an emission tax at the national-level does not guarantee that overlapping state-level policies are immune to complete leakage. For large states subject to a national CO_2 tax or no national climate policy, modest emission reduction goals can be achieved with either a state-level CO_2 tax or a state-level RPS, though the cost should be lower under a state-level CO_2 tax. The maximum feasible reduction in national emissions, however, is higher for a state-level RPS compared to a state-level CO_2 tax.

Under a national cap-and-trade program with a carve-out provision, a state of any size can achieve a reduction in national emissions by setting a tighter state cap because the sum of the national and state emissions caps has been reduced. Examining cost-effectiveness, we find that a national cap-and-trade policy with a carve-out provision will cost less than a national CO_2 tax when states pursue more stringent overlapping policies. This occurs because reshuffling or leakage of emissions within the market raises the national emissions permit price (in order to keep emissions in the rest of the nation constant). Consequently, for any given reduction in national emissions, the increase in emissions in the rest of the market is smaller under a national cap-and-trade program with a carve-out than under a national CO_2 tax and therefore the cost of achieving that reduction in emissions is lower under the national cap-and-trade program with a carve-out. If a tighter state cap does cause an increase in emissions in the rest of the market, then emissions outside the market must fall, increasing prices for consumers outside the market. Under a CO_2 tax, emissions and cost to consumers outside the market are both unaffected by the state policy. Thus, while a national cap-and-trade policy with a carve-out is less costly for the nation as a whole when states implement tighter caps than the equivalent national and state CO_2 taxes, a national cap-and-trade with a carve-out will lead to higher costs for consumers outside the market than would a national CO_2 tax, which

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17. That a state-level policy is unable to affect national emissions under a national emissions cap *without* carve-out is well known (See Burtraw and Shobe, 2009; Goulder and Stavins, 2011a, e.g.)).

18. The one possible combination among these policies that we do not analyze is a state RPS with national cap and trade with state carve-out. This option is excluded because it would be very difficult in practice to determine what the minimum stringency of a state's RPS ought to be to qualify the state to be carved out of a national cap and trade regime. Conversely, when the state's policy is an emissions tax or lower emissions cap, the requirements for a state to be carved out are clear.

could create political opposition to allowing individual states to be a carved out of a national cap-and-trade program.

Extending the model to consider overlapping policies in multiple states within a market together with a national-level policy, we find that, holding the total quantity of renewable generation within the market fixed, the size threshold for a state to affect national emissions through a CO_2 tax diminishes as more states within the market adopt targets for renewable energy consumption. If other states in the market have CO_2 taxes and there is a national CO_2 tax, a state of any size could cause additional emissions reduction by adding a state CO_2 tax. If there is a national cap-and-trade policy with a carve-out provision, the climate policies of other states do not affect the ability of the state to reduce national emissions by setting a tighter cap. Extending to a multi-sectoral or economy-wide context, we conclude that the efficacy of a state-level policy in reducing national emissions will change depending on how the relative size of the state changes with the widening scope of the policy. Given the global effects of CO_2 emissions, our results also speak to the interactions that could take place when global policies overlap national policies or state policies overlap local policies and product markets are larger than the smaller jurisdiction. Our framework can additionally be extended to consider other policies such as emission intensity standards, subsidies for renewable energy and border adjustment policies.

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APPENDIX A: PROOF OF PROPOSITION 1

Proposition 1 *For any pre-policy generation portfolio with fossil fuels, RPS-qualifying renewables, and non-qualifying near-zero carbon resources, there exists a range of relative state sizes such that a sufficiently stringent state RPS policy may reduce CO_2 emissions, but a state CO_2 tax cannot when there is no national policy or when there is a national CO_2 tax.*

Proof. Assume for simplicity that the utility functions are continuous, increasing, and strictly concave and the cost functions are continuous, increasing, and strictly convex.

Let $\rho \in [0,1]$ indicate the size of the state relative to the market. As state size is measured by the state's share of the market's electricity consumption pre-state policy, in-state consumption is $q^{s0} = \rho q^{M0}$, the 0 superscript indicating pre-state-policy. Let $\underline{R}$ represent the share of market consumption that could be met with existing qualifying renewable generation alone, $\underline{R} q^{M0} = q_r^{M0}$. Then $\underline{R}$ also represents the largest state size such that the state can consume only qualifying renewables *and* satisfy all pre-policy demand, i.e. if $q^{s0} \leq \underline{R} q^{M0}$ then all demand in state can be served by existing qualifying renewables, q_r^{M0}. Let $\bar{R}$ be such that $\bar{R} q^{M0} = q_r^{M0} + q_z^{M0}$ and in-state consumption be such that $q^{s0} \leq \bar{R} q^{M0}$. Then $\bar{R}$ is the share of zero-carbon resources in the market as well as the largest state size such that the state can consume only zero-carbon resources *and* satisfy all pre-policy demand.

As explained in section 3.1.1, when $\rho < \bar{R}$, a state CO_2 tax cannot reduce emissions when there is a national CO_2 tax $T^n \geq 0$ as there are sufficient zero-carbon resources in the market to satisfy demand in the state with no change in production or emissions and thus no change in tax burden. Also, if the national policy is a CO_2 tax or if there is no policy, the rest of the nation's production and emissions will be unaffected by any state policy.

The remainder of the proof will proceed in three steps. In step 1, we demonstrate that for a sufficiently large state, $\rho > \underline{R}$, there exists an RPS stringency, α, such that the qualifying renewable resources required by the policy if state consumption remained unchanged would be larger than existing quantity of qualifying renewables, $\alpha \rho q^{M0} > q_r^{M0}$. In step 2, we note that if α is such that $\alpha \rho q^{M0} > q_r^{M0}$, then the RPS constraint binds and the shadow price on the constraint γ^s (a.k.a. the REC price) must be larger than zero. In step 3, we demonstrate that given $\alpha \rho q^{M0} > q_r^{M0}$, the RPS policy will cause the price in the rest of the market, p^m to decline which will reduce the quantity of generation from coal and natural gas and therefore reduce emissions.

Step 1: Prove that there exists an $\alpha \in (0,1)$ such that $\alpha \rho q^{M0} > q_r^{M0}$ when $\rho > \underline{R}$:

Proof. At $\rho = \underline{R}$, $\underline{R} q^{M0} = q_r^{M0}$. For $\rho > \underline{R}$, $\rho q^{M0} > q_r^{M0}$. For α sufficiently close to one, $\alpha \rho q^{M0} > q_r^{M0}$. $\square$

Thus, there exists an RPS requirement, α, that will force the state to either increase generation from renewable resources beyond what was produced in the market pre-policy or reduce consumption.

Step 2: If α is such that $\alpha \rho q^{M0} > q_r^{M0}$ and $\alpha < 1$, then existing renewables cannot satisfy the RPS constraint and the RPS constraint will bind, causing the shadow price (price of a REC in-state), γ^s, to be positive.

Step 3: Prove that $p^m < p^0$ for $\alpha > \hat{\alpha}$ where $\hat{\alpha}$ is such that the RPS just binds ($\hat{\alpha} \rho q^{M0} = q_r^{M0}$):

Proof. If $\alpha < 1$, $\gamma^s > 0$ and $q^s > 0$, then the binding RPS constraint causes non-qualifying fuels (coal, natural gas and non-qualifying zero-carbon fuels, defined collectively as q_{nq}) to be used in-state, $q_{nq}^s = q_c^s + q_{ng}^s + q_z^s > 0$ (otherwise, the RPS constraint, which requires $q^s = A q_{nq}^s$, $A = \dfrac{\alpha}{1-\alpha}$, would dictate that $q^s = 0$ also). From the first order conditions, if generation from renewable fuels is sold both in-state and to the rest of the market, $q_r^s > 0$ and $q_r^m > 0$, then it must receive the same price in both: $p^s + \gamma^s = p^m$, where $p^s + \gamma^s$ is the price received for renewable generation in-state and p^m is the price that all types of generation receive out-of-state. If $p^s + \gamma^s = p^m$ then $p^s - A\gamma^s < p^m$ since $A > 0$. Since $p^s - A\gamma^s$ is the price received in-state for all non-qualifying fuels, $p^s - A\gamma^s < p^m$, implies producers would only want to sell non-qualifying fuels to the rest of the market where the price is higher so $q_{nq}^s = 0$ and $q_{nq}^m > 0$, but this is a contradiction. Thus, $q_r^s > 0$, $q_r^m = 0$, $q_{nq}^s > 0$ and $q_{nq}^m > 0$ and $p^s - A\gamma^s = p^m$, or in other words, if non-qualifying resources are consumed in both regions, they must receive the same price in each region. Thus if p^m declines, then the strictly increasing and convex cost curves ensure that generation from coal and natural gas in the market declines. With $\alpha > \hat{\alpha}$, to meet the RPS constraint either consumption declines, $q^s < \rho q^{M0}$, renewable generation increases, $q_r^s > q_r^{M0}$, or both. Suppose that consumption and renewable generation increase, $q^s \geq \rho q^{M0}$ and $q_r > q_r^{M0}$. If $q_r > q_r^{M0}$, $p^s + \gamma^s \geq p^0$ by strict convexity of costs. If $q^s \geq \rho q^{M0}$, then $p^s \leq p^0$ by strict concavity of utility. Together, it must be that $p^0 \geq p^s$, which implies $p^0 > p^s - A\gamma^s = p^m$.

In the other case, if consumption declines, $q^s < \rho q^{M0}$, then $p^s > p^0$ by strict concavity of utility. $\gamma^s > 0$ implies $p^s + \gamma^s > p^0$, so it must be that renewable generation increases $q_r > q_r^{M0}$. At $\hat{\alpha}$ where the RPS just binds, $\rho q^{M0} - q_r^{M0} = \hat{q}^s - q_r^{M0} = \hat{q}_{nq}^s$, $\hat{q}_{nq}^m = q_0^m$, and $\hat{q}_{nq}^s + \hat{q}_{nq}^m = q_{nq}^{M0}$. $\hat{q}$ indicates the equilibrium quantity at $\hat{\alpha}$.

We have assumed that $q^s < \rho q^{M0}$ and $q_r > q_r^{M0}$, which imply $q_{nq}^s = q^s - q_r < \rho q^{M0} - q_r^{M0} = \hat{q}_{nq}^s$. Suppose $q_{nq}^m \leq \hat{q}_{nq}^m = q_0^m$. Since $q^m = q_{nq}^m$, $p^m \geq p^0$ by strict concavity of utility. But if $p^m \geq p^0$, then $q_{nq}^s + q_{nq}^m < q_{nq}^{M0}$, which implies $p^m < p^0$ by strict convexity of costs, a contradiction. Therefore, $q^m = q_{nq}^m > \hat{q}_{nq}^m = q_0^m$ and, as long as $q_{nq}^M < q_{nq}^{M0}$, we have $p^m < p^0$ by strictly increasing and concave utility and strictly increasing and convex costs, as desired. $\square$

With $p^m < p^0$, generation from coal and natural gas decreases ($q_c^M < q_c^{M0}$ and $q_g^M < q_g^{M0}$) by strictly increasing and convex costs. Therefore CO_2 emissions in the market decline. $\square$

APPENDIX B: PROOF OF PROPOSITION 2

Proposition 2 *If there is no national climate policy in place or if there is a national CO_2 tax, and if there are zero-carbon resources that are not RPS-qualifying renewables, then the maximum reduction in emissions that can be achieved by a state RPS will exceed the maximum reduction that can be achieved by a state CO_2 tax for states participating in markets with other states.*

Proof. Assume for simplicity that the utility functions are continuous, increasing, and strictly concave and the cost functions are continuous, increasing, and strictly convex.

If there is a national CO_2 tax or if there is no national climate policy (i.e. $T^n = 0$), the rest of the nation's production and emissions will be unaffected by any state policy. If a state RPS

demands 100 percent renewables, then coal, natural gas, and non-qualifying zero-carbon fuels are used only in the rest of the market and the following first order conditions determine their output:

$$p^m = \frac{\partial}{\partial q_c^m} u^m(q_c^m + q_g^m + q_z^m) = \frac{d}{dq_c^m} c_c(q_c^m) + e_c T^n \tag{5}$$

$$p^m = \frac{\partial}{\partial q_g^m} u^m(q_c^m + q_g^m + q_z^m) = \frac{d}{dq_g^m} c_g(q_g^m) + e_g T^n \tag{6}$$

$$p^m = \frac{\partial}{\partial q_z^m} u^m(q_c^m + q_g^m + q_z^m) = \psi \tag{7}$$

ψ is the Lagrange multiplier on the constraint $q_z^m + q_z^s \le Q_z^M$. If the price in the rest of the market is positive, $p^m > 0$, then the full capacity of non-qualifying zero-carbon generation will be utilized, $\psi > 0$ and $q_z^m = Q_z^M$. If not, $p^m = 0$ and $q_z^m \le Q_z^M$. If we assume (i) $\frac{d}{dq_c^m} c_c(0) > 0$ and (ii) $\frac{d}{dq_g^m} c_g(0) > 0$, then when $p^m = 0$, $q_c^m = 0$ and $q_g^m = 0$.

If a state CO_2 tax is sufficiently high, then only zero-carbon resources will be used in-state and only coal and natural gas will be used in the rest of the market. Generation of coal and natural gas are then determined by the first order conditions:

$$p^m = \frac{\partial}{\partial q_c^m} u^m(q_c^m + q_g^m) = \frac{d}{dq_c^m} c_c(q_c^m) + e_c T^n \tag{8}$$

$$p^m = \frac{\partial}{\partial q_g^m} u^m(q_c^m + q_g^m) = \frac{d}{dq_g^m} c_g(q_g^m) + e_g T^n \tag{9}$$

If we assume (iii) $\frac{\partial}{\partial q_c^m} u^m(0) > \frac{d}{dq_c^m} c_c(0) > 0$ and (iv) $\frac{\partial}{\partial q_g^m} u^m(0) > \frac{d}{dq_g^m} c_g(0) > 0$, then generation from coal and natural gas will always occur, $q_c^m > 0$ and $q_g^m > 0$.

If $q_c^m = 0$ and $q_g^m = 0$ under the most stringent state RPS, CO_2 emissions in the market will be zero by assumptions (i) and (ii). Conversely, even with a very high state CO_2 tax, emissions will always be positive because, in that case, $q_c^m > 0$ and $q_g^m > 0$ by assumptions (iii) and (iv).

If $q_c^m > 0$ and $q_g^m > 0$ under the most stringent RPS, then $q_z^m = Q_z^M$. If q_c^m and q_g^m solve equations (5) and (6) and we were to remove the non-qualifying zero-carbon generation being used, then $\frac{d}{dq_c^m} c_c(q_c^m) + e_c T^n < \frac{\partial}{\partial q_c^m} u^m(q_c^m + q_g^m)$ and $\frac{d}{dq_g^m} c_g(q_g) + e_g T^n < \frac{\partial}{\partial q_g^m} u^m(q_c^m + q_g^m)$ by strict concavity of utility. Note that except for the inequality, these equations are equations (8) and (9). By continuity, concave strictly increasing utility, and convex strictly increasing costs, there exists a $\hat{q}_c^m > q_c^m$ and a $\hat{q}_g^m > q_g^m$ such that equations (8) and (9) are satisfied. Thus, the most stringent RPS induces less generation from fossil fuels and therefore fewer emissions than would an infinite CO_2 tax because, unlike under an infinitely high state CO_2 tax, zero-carbon generation is available to out-of-state consumers under the most stringent RPS, which replaces much of their demand for generation from coal and natural gas. $\square$

APPENDIX C: DATA AND CALIBRATION

We assume the supply and demand curves are linear and represent a long term response to long-term price trends in the market. Thus, the demand curve represents the average consumer response to price changes over the long term, and the supply curve is modeled as a long-term adjustment by producers who may be investing in new generation capacity. To ensure our demand and supply functions have the required interpretation, we utilize data from the Annual Energy Outlook 2011 (AEO2011) published by the U.S. Energy Information Administration (EIA) which focuses on the factors that shape the U.S. energy system over the long term. Our baseline pre-policy scenario utilizes 2009 data. Using the reference case, the high demand growth and the low demand growth side cases, we compute the elasticity of supply implied by the difference between the reference case and the side cases. We compute the elasticity of demand using the reference case and a side case developed to examine the effect of a clean energy standard for Senator Jeff Bingaman.

The baseline price, quantities, and elasticities used to calculate the parameters of the supply and demand curves are shown in Table 1. As our model contains three regions, state, rest of the market, and rest of the nation, we compute three demand curves. In all scenarios, we assume that a market consumes 10 percent of the national electricity consumed. We consider two possible sizes of the state relative to the market, 25 and 75 percent. If the state is 25 percent of the market, then 25 percent of the pre-policy market generation is consumed in the state. The price and elasticity of demand are assumed to be the same in each region. There are also two supply curves, one for the market and one for the rest of the nation. We assume resources are uniformly distributed across the nation and that the elasticity of supply is the same in all regions.[19]

Table 1: Parameters of the Model

Parameter	Interpretation	Value
p^0	Initial Price ($/KWh)	0.098
q^0	Initial Total Generation (KWh)	3.98E + 12
q_z^0	Initial Non-Qualifying Zero-Carbon Gen. (KWh)	1.13E + 12
q_r^0	Initial Renewable Generation (KWh)	1.45E + 11
q_g^0	Initial Natural Gas Generation (KWh)	9.31E + 11
q_c^0	Initial Coal Generation (KWh)	1.77E + 12
ε	Demand Elasticity	−0.2
ε_r	Renewables Elasticity	1.49
ε_g	Natural Gas Elasticity	2.57
ε_c	Coal Elasticity	1.10

Lastly, the Environmental Protection Agency indicates that CO_2 emissions are approximately 1.125 tonnes/MWh of coal generation and 0.5625 tonnes/MWh of natural gas generation.[20] Thus, the CO_2 emissions per MWh of coal generation are roughly double the CO_2 emissions per MWh of natural gas generation.

19. The uniform distribution of resources only affects our results in that it sets the share of market-wide electricity a state must consume to be considered large (See Section 2.3).

20. http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html

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