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Estimating the implied cost of carbon in future scenarios using a CGE model: The Case of Colorado

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ABSTRACT

Using Colorado as a case study, we develop a state-level computable general equilibrium (CGE) model that reflects the roles of coal, natural gas, wind, solar, and hydroelectricity in supplying electricity. We focus on the economic impact of implementing Colorado's existing Renewable Portfolio Standard, updated in 2013. This requires that 25% of state generation come from qualifying renewable sources by 2020. We evaluate the policy under a variety of assumptions regarding wind integration costs and assumptions on the persistence of federal subsidies for wind. Specifically, we estimate the implied price of carbon as the carbon price at which a state-level policy would pass a state-level cost-benefit analysis, taking account of estimated greenhouse gas emission reductions and ancillary benefits from corresponding reductions in criteria pollutants. Our findings suggest that without the Production Tax Credit (federal aid), the state policy of mandating renewable power generation (RPS) is costly to state actors, with an implied cost of carbon of about $17 per ton of CO2 with a 3% discount rate. Federal aid makes the decision between natural gas and wind nearly cost neutral for Colorado.

1. Introduction

Economic models to analyze climate change policies typically adopt a global or national perspective. But policy activity is occurring with increasing frequency at a sub-national level. For example, 29 U.S. states have adopted renewable portfolio standards (RPS) and a variety of other policies, including cap and trade systems, feed-in tariffs, and technology standards are also being pursued at the state and local levels (EIA, 2012).[1]

For regional[2] decision makers, quantitative models with a regional perspective have several advantages. First, the startup costs to build and maintain the model are lower. Moreover, adopting a sub-national perspective makes it possible to simulate outcomes with a greater degree of detail across sectors and household groups than is typically feasible in models describing an entire country. Finally, by emphasizing outcomes at the jurisdictional scale, such models allow decision makers to evaluate the effect of proposed policies in terms of their effect on constituent interests.

The paper develops a state-level computable general equilibrium (CGE) model that can be used to assess economy-wide costs in Colorado associated with potential energy policies. The model is calibrated using 2010 data for the state of Colorado, though it could serve as a template for other states. The CGE model is embedded within a cost-benefit framework that accounts for the full economic burden ensuing from a given policy without imposing an estimate for the marginal externality cost of carbon emissions. This is used to solve for what we call the Implied Carbon Price (ICP), the breakeven price at which a specific policy would pass a hypothetical cost-benefit test. The computed ICP is closely related to the CO2 abatement cost, but it also accounts for the economic benefits that accrue to constituents of the region as a consequence of achieved reductions in pollutants in the region, so-called "ancillary benefits", and it accounts for the efficiency loss associated with "leakage" when action to address a trans boundary externality is implemented unilaterally.[3]

Colorado provides an interesting case study because the Colorado RPS is one of the most aggressive policies in the United States.[4] In

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[1] This does not include West Virginia's Renewable and Alternative Energy Portfolio Standard.
[2] For the remainder of the paper, "regional" refers to a general but unspecified sub-national jurisdiction. For example, a state, province or a municipality.
[3] When restrictions are placed on economic activities that occur within a narrow region, regulated actors have incentive to relocate to unrestricted regions. Because the location of emissions doesn't matter for a global pollutant, this diminishes the overall environmental benefit, and thus undermines the policy's intended effect. "Leakage" quantifies this loss.
[4] Other notable legislation includes HB1365, passed in 2010, which mandates the transition of 900MW of coal capacity to natural gas by 2017.

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2004, Colorado became the first state to pass an RPS by ballot initiative, and subsequent legislation (in 2007, 2010, and 2013) strengthened the policy. The current mandate calls for 30% renewable energy for investor-owned utilities, 20% for large electric cooperatives, and 10% for remaining sources. Averaged across the electricity sector, the policy requires approximately 25% of electricity sales to come from renewables by 2020.

The paper estimates the ICP for the Colorado RPS. The ICP is highly sensitive to assumptions about interconnection and variability costs,[5] as well the future of the recently renewed federal production tax credit (PTC) for renewable energy sources. Because this is a state-level analysis for Colorado we do not include impacts outside of Colorado of taxes paid to support federal subsidies.[6] For state-level decision makers, the federal PTC is an external subsidy not internalized in state-level cost-benefit analysis. Computing the ICP without the PTC reveals the full economic burden of the policy. It also highlights the critical role federal subsidies play in supporting and encouraging state-level action. Absent the PTC, with a 5% discount rate the RPS policy has an ICP of $13 per ton of CO2 if variability costs are high but only about $2 if variability costs are low. At the same time, the full economic cost is less than the $42 per ton CO2 central estimate of the Social Cost of Carbon that comes out of the most recent Interagency Working Group Report on Social Cost of Greenhouse Gases (IWGSCGG, 2016). With the PTC, the ICP drops to about $4 per ton if variability costs are high and becomes negative if variability costs are low. Thus, federal aid makes the decision between natural gas and wind nearly cost neutral.

Initiatives by the EPA to use its authority under the Clean Air Act to regulate carbon emissions from new and existing power plants may significantly modify the landscape for state energy policy, including costs and benefits attributable to an RPS. Nevertheless, for these reasons, we have decided to consider a model that abstracts from the potential future impacts of these changes. First, there remains flexibility (and uncertainty) regarding how states will actually respond. This makes it hard to model the potential policy interactions. Second, one of our goals is to evaluate the costs of a state-level RPS policy in a case study with general applicability. It is therefore arguably more interesting to consider the Colorado policy absent the rule changes.

The paper contributes to the growing literature that considers the cost of RPS policies. Several papers use energy-economy models to evaluate the impact of RPS policies at the national level. Of these, Palmer and Burtraw (2005) and Kydes (2007) both use detailed bottom-up partial equilibrium energy models. Palmer and Burtraw (2005) find that the cost of RPS policies are relatively low for mandates below 15%, but significantly higher beyond this. Kydes (2007) concludes that a national 20% RPS mandate would raise electricity prices by 3%. The relationship between cost and penetration level is related to intermittency. Gullì and Balbo (2015) pursue an econometric approach in estimating the impact of intermittency of renewable energy in Italy. They conclude that results are not generalizable; researchers need to use intermittency costs unique to their area of interest.

At a national level, Hwang and Lee (2015) develop a CGE model for South Korea to examine impacts of changes in electricity markets with greater penetration of renewable energy. They conclude that forward contracts should be implemented to promote competition in distribution and generation sectors. Antoni et al. (2015) develop a German data set that allows estimation of employment and wage differentials between renewable energy and other sectors. Policies encouraging renewable energy result in sectoral wage premiums for this. In Yamazaki and Takeda (2016) CGE model for the Japanese nuclear sector, introducing a renewable energy sector inhibits economic activity.

Hillebrand et al. (2006) and Lehr et al. (2012) analyze German renewables policy using an input-output model, and conclude that the policy generates employment gains in the near term, but long-term losses. These effects were less than 1% in Hillebrand et al. (2006) but as much as 10% in Lehr et al. (2012), due to liberal expectations of increase in exports. Ragwitz et al. (2009), estimate that EU-wide renewable energy support policies have a positive impact on employment. The Berkeley Energy and Resource (BEAR) Model (Roland-Holst, 2008; Roland-Holst and Kahrl, 2009), a state-level CGE model, has been used to model renewable energy policy in California finding employment gains of 1–2%.

To our knowledge, the only CGE paper in the peer-reviewed literature to analyze a sub-national RPS is Böhringer et al. (2012), using a static, multi-province CGE model to study the employment impacts in Ontario of renewable energy policies implemented in the province. Among the policies considered is an RPS with a domestic content requirement. The policy is calibrated to achieve a renewable electricity market share of 15%. A key result of the paper is that renewable policies lead to employment increases in green sectors, which are more than offset by employment losses elsewhere. Under the RPS, total provincial employment decreases by 0.28%. A considerable grey literature studies the economic impacts of state-level RPS policies. Chen et al. (2009) review 28 cost-impact modeling assessments for existing or proposed RPS policies. The reviewed studies are often produced by advocates, and the rigor is typically low.

A limitation of the Böhringer et al. study, which the authors emphasize, is that it focuses solely on costs, ignoring the environmental benefits side of the ledger. Given the global nature of climate impacts, it is hard to say what the appropriate carbon price should be for evaluating energy policy at the level of an individual province or state. One answer is to say it is near zero since most climate damages fall outside the jurisdiction. But if the carbon price is zero, can we rationalize the diffusion of sub-national climate policies in the U.S. and elsewhere? To allow policy-maker judgment about the value of CO2 emission reductions, we reframe the question by first accounting for the truly local (ancillary) benefits, then solving for the break-even carbon price at which the proposed policy would pass a hypothetical cost-benefit test.

Discussions of sub-national renewable initiatives are influenced by non-economic perspectives. Winfield and Dolter (2014) survey analyses of Ontario's Green Energy and Green Economy Act (GEGEA). Following Dryzek (2013) they divide researchers into groups: “market fundamentalists” (who oppose government intervention), “economic rationalists” (who employ formal economic models), and “ecological modernists” (who seek to restructure the economy in an environmentally sustainable way). The latter group complement the approach in this paper. Among Winfield and Dolter (2014)'s modernists, Pollin and Garret-Peltier (2009) focus on eight green energy areas and find gains of 32,200 jobs over 10 years and conservation of 11.8 GW of nonrenewable electricity production. In addition, Weis and Partington (2011) use a bottom up engineering model and conclude that the impact of GEGEA will have a minimal impact on electricity prices initially and by 2025, there will be no impact on prices.

There is also an important literature that discusses potential pitfalls with state-level climate policy. Goulder and Stavins (2010) review the case for and against state climate action. They find that federal and state policies can either reinforce each other or can be in conflict. This implies that federal policy has to be sensitive to state objectives, and that state policy should take into account the landscape of existing federal policies. Shobe and Burtraw (2012) revisit the implications of a federal structure on the design and location of optimal climate policy. They argue that there is a greater role for state action than has typically been acknowledged by economists previously. Bushnell et al. (2008)

[5] Variability costs refer to the system wide cost associated with redundant capital needed to ensure system reliability when a fraction of generation sources depend on intermittent factors like sunlight or wind.

[6] We also do not include benefits such as reductions in CO2 that are inherently not regional and purchases made outside of the state. Even the scenario without the PTC is affected by these subsidies due to federally funded research and development and other subsidies that reduce the price of renewables.