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Interacting policies in power systems: Renewable subsidies and a carbon tax☆

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ABSTRACT

Without careful planning and design, energy policies like carbon taxes and renewable subsidies like production tax credits undercut one another in unanticipated ways. We examine how a carbon tax interacts with PTCs by simulating an electricity market using the IEEE RTS model with a carbon tax of \$38/tonCO2e and a PTC of \$23/MWh. The results show that PTCs work against the carbon tax by both lowering average energy prices and altering the generator dispatch.

1. Introduction

Power plants are the largest stationary sources of greenhouse gas (GHG) emissions. In 2013, coal and natural gas power plants in the United States contributed over 29% of total U.S. GHG emissions (Agostini et al., 1992; Contreras et al., 2016). A carbon tax is often presented as the most economically efficient approach to limit these emissions (Newcomer et al., 2008). It has recently started to gain support from unanticipated sectors like the oil and gas industry (Rosenberg, 2017) and 12 countries and the Canadian province of British Columbia have implemented carbon taxes with values ranging from \$1/tonCO_{2e} in Mexico to \$130/tonCO_{2e} in Sweden (The World Bank, 2015b).

While the effectiveness of a carbon tax is measured in terms of emissions saved per dollar and revenue flows, the results can vary significantly with the presence/absence of interacting energy policies such as programs that promote low-carbon resources. One example is production tax credits (PTCs) for wind power. PTCs can reduce the operational costs of wind below that of other generators. For example, each MWh of wind generated in the United States currently qualifies for a \$23/MWh PTC.

When energy policies with different objectives are simultaneously enacted in an electricity market, there can be unanticipated interactions. In this work, we build on the very few works in the literature (Contreras et al., 2015; Downward, 2010; Newcomer et al., 2008) that analyze the effectiveness of a new environmental policy in a power system with existing legacy policies. While the prior works generally focus on cap-and-trade mechanisms and transmission congestion, we examine how a carbon tax interacts with PTCs in electricity market operations. We use the IEEE RTS model and apply a \$38/tonCO_{2e} carbon tax to a real-time electricity market with and without PTCs. We then perform a 24-h unit commitment (UC) followed by a DC optimal power flow (DCOPF), and compare emissions savings and revenue flows for each scenario.

As the ultimate effectiveness of any energy policy depends on how it interacts with other policies in practice, this study provides important insights into policies targeted towards decarbonizing the energy system. In addition, this work develops a framework for including such dispatch interactions that could be used in long-term investment decision models. When such models are applied to actual power systems, they can help accurately inform policymakers on whether to choose a PTC, a carbon tax, or a mixture of both.

This article is organized as follows: subsection 1.1 explains our rationale, section 2 provides the theory and calculations, section 3 explains the results, section 4 discusses them and section 5 concludes the work and outlines further research directions

1.1. Rationale: subdies, taxes and interactions

Governments use subsidies, like PTCs, to alter the price of goods and steer economic, social, and political outcomes. They generally reduce the costs for consumers and suppliers. For example, since 2004, the United States has used PTCs to incentivize the penetration of wind power in the electric sector from a few thousand MW in 2000 to almost

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75,000 MW today. Other types of subsidies are used throughout the sector to promote other sources of low-carbon power.

Similarly, a carbon tax (Baumol, 1972; Pigou, 1932) is an environmental tax to change market prices to internalize environmental harms. A carbon tax can reduce emissions by both price-induced demand reduction (electricity is more expensive, so people use less) and fuel substitution. Results from practice have demonstrated that carbon taxes can be effective at reducing carbon emissions; a carbon tax contributed to a 2% emissions reduction in Norway for a period of nine years (1990–1999) (Agostini et al., 1992; Bruvoll and Larsen, 2004; Lin and Li, 2011), a 1.69% emissions reduction in Finland for a period of 11 years (1997–2008) (Agostini et al., 1992; Bruvoll and Larsen, 2004; Lin and Li, 2011), and a 13% average emissions reduction in British Columbia for a period of six years (average of 2000–2007 pretax emissions vs. average of 2008–2013 post tax emissions) (Komanoff and Gordon, 2015).

Carbon taxes and their interactions with other socio-economic taxes and policies, like labor taxes, are a well-studied phenomenon (Bovenberg and Goulder, 1996; Goulder, 1992, 1995; Goulder et al., 1996; Metcalf, 2009; Metcalf and Weisbach, 2009; Parry, 2003; Williams, 2002). However, their interactions with power systems operations and existing legacy energy policies remain a critical gap area. For example, if implementing both a carbon tax and PTCs, policy interactions may undermine their collective effectiveness. For example, PTCs may (1) change the generator dispatch order and/or (2) lower the average energy price and thus increase demand:

1. In a power system with PTCs, wind generators will become cheaper to operate and they may bid into the real-time electricity market at a very low (or even negative) price. Thus, they will always be dispatched at their maximum rated capacity as long as there is sufficient transmission capacity. Keeping everything else constant, this could create a “large price spread” between the wind generator’s offers and those from traditional fossil fuel generators. Such a price spread could alter the dispatch order and change the fuel mix of the dispatched resources. In practice, PTC subsidized generators (e.g. wind) often already operate at their maximum rated capacities. Introducing a carbon tax would make carbon-intensive resources like coal, natural gas, and oil more costly, but as they are already relatively more expensive, in the shorter operational term, it might not change the dispatch order. Ideally, a carbon tax would create a market signal to remove the high-carbon generators from the fuel mix, but in a system with both PTCs and carbon taxes total system costs increase but the dispatch order would not change.
2. PTCs also lower the average energy price by subsidizing certain generation types. These subsidies can increase electricity demand as lower generator costs shift the supply curve downward, resulting in decreased market prices and increased demand. However, this is opposite to how a carbon tax works, where the tax increases prices and thus decreases demand. This interaction between PTCs and a carbon tax can diminish the effectiveness of both policies.

2. Theory/calculation

The simulation methodology used to examine the interactions between a carbon tax and PTCs in power system and electricity market operations is illustrated in Fig. 1. The simulations are performed for a real-time electricity market, however, with slight modifications, the methodology can also be used to model a day-ahead market. Furthermore, no transmission congestion was considered in this work, but it will be explored in future work.

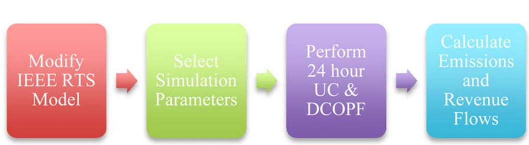

Fig. 1. Simulation methodology: after careful selection of IEEE RTS model and simulation parameters, a 24-h Day Ahead (DA) unit commitment and dispatch is performed, and the resulting emissions and revenue flows are calculated.

2.1. IEEE RTS model

To illustrate the interactions of a carbon tax and PTCs, and to account for computation limitations and data availability, we used the IEEE RTS model (Billinton and Allan, 2012). The generator, load, bus, and branch data can be found in (Billinton and Allan, 2012; University of Washington Electrical Engineering, 2017) and the market bidding data, with and without a carbon tax and PTCs, is listed in (Bhandari et al., 2016). The IEEE RTS model is an older model with an outdated generation mix; it contains few renewable generation sources nor any natural gas generators. To remedy this deficiency the oil generators at bus 7 were converted into wind generators and generators U197 (at bus 13) and U12 (at bus 15) were converted to natural gas generators.

2.1.1. Wind generators

For the wind generators at bus 7, it was assumed that the PTCs were reflected in the b-coefficients of their cost curves, and that their “a” and “c” coefficients were similar to those of existing hydro-generators. Removal of the PTCs may or may not change the operational costs of wind by $23/MWh (PTC amount). Therefore, to illustrate the sensitivity of the results to the operational costs of wind, we also present results if the removal of PTCs would change the operational costs of wind to $10/MWh and $30/MWh.

2.1.2. Natural gas generators

The operational costs of the natural gas generators are unaffected by PTCs. It was assumed that the cost of the natural gas generators was five times cheaper than that of oil as described in (United States Energy Information Administration, 2015b,c).

2.2. System parameters

The following system parameters were used in the simulations:

2.2.1. Carbon tax and emission factors

A carbon tax of \$38/tonCO_{2e} was used. This is close to the U.S. Environment Protection Agency’s estimate of the social cost of carbon (United States Environmental Protection Agency, 2013). Since power plant emissions differ based on fuel type, a marginal emissions factor of 2000 lbCO_{2e}/MWh for coal, 1500 lbCO_{2e}/MWh for oil, and 1200 lbCO_{2e}/MWh for natural gas generators were used, similar to those in the following references (Hawkes, 2010; The World Bank, 2015a; United States Energy Information Administration, 2015a). Based on these emissions factors, the effective carbon tax was $34/MWh for coal, $25/MWh for oil, and $20/MWh for natural gas as shown in Table 1. This tax is added to the b-coefficient of the generator’s cost curves.

Table 1
Power plant type, emissions factor and carbon tax.

Power Plant Type	Emissions Factor $\left(\frac{lbCO_{2e}}{MWh}\right)$	Carbon Tax $\left(\frac{\$}{tonCO_{2e}}\right)$	Effective Carbon Tax $\left(\frac{\$}{MWh}\right)$
Coal	2000	38	34
Natural gas	1200	38	20
Oil	1500	38	25
Renewable	N/A	N/A	N/A
Hydro	N/A	N/A	N/A
Nuclear	N/A	N/A	N/A