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The structural impact of renewable portfolio standards and feed-in tariffs on electricity markets

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ABSTRACT

The capacity of renewable energy sources (RES) has grown rapidly worldwide, and this growth has benefited from such support schemes as renewable portfolio standards (RPS), feed-in tariffs (FITs), and market premia (MP). Previous research concentrated on comparing the effectiveness of these policy instruments at driving RES investment, but the field's focus has shifted toward evaluating how they structurally affect electricity markets. In particular, research has sought to assess how much RES support schemes contribute to achieving the three main objectives of electricity policy, the affordability, reliability, and sustainability of electricity supply. In this work, we quantitatively compare RPS, FIT, and MP schemes in terms of those criteria by simulating the impact of all three support schemes via a dynamic long-term capacity investment model. We find that each support scheme increases RES penetration and thereby reduces carbon dioxide (CO_2) emissions. Whereas MP and FITs can achieve this outcome at lower cost, RPS delivers more robust results.

1. Introduction

In 2012, investment in renewable energy sources (RES) amounted to dollar 244 billion globally, a sixfold increase over 2004 levels (UNEP, 2013). The corresponding 85-gigawatt (GW) increase in RES generation capacity is due mostly to wind and solar photovoltaic (PV) power (REN21, 2013). Many researchers attribute this investment boom to various RES support schemes – including feed-in tariffs (FITs) and renewable portfolio standards (RPS) (Couture & Gagnon, 2010) – through which governments attempt to achieve specific energy policy goals (IEA, 2011). There has been a global proliferation of RES support schemes; by early 2013, 127 countries had adopted at least one such scheme (REN21, 2013). More than 70 countries and nearly 30 states or provinces have adopted a FIT (REN21, 2013), the most widespread RES support scheme. The next most frequently employed scheme is RPS, adopted by 22 countries and 54 other jurisdictions (REN21, 2013). Studies have assessed the effectiveness of these different policy tools at driving RES investment (e.g., Haas et al., 2011; Mormann, 2012), and FIT schemes are often found to be more effective than RPS and other, more market-oriented schemes (Butler & Neuhoff, 2008). Yet contemporary debate indicates that attention is shifting away from that first-order effect and toward such second-order effects as the cost of these support schemes, market integration of the particular renewable sources supported, and price effects (The Economist, 2013). These aspects are not well understood.

In this paper we use a long-term capacity investment model to quantify the structural impact of the main support schemes – RPS, FIT, and market premia (MP) – on electricity markets. We assess and compare these RES support schemes along the three dimensions of energy policy highlighted by the International Energy Agency (IEA): affordability,[1] availability,[2] and sustainability (IEA, 2011).

The paper proceeds as follows. In Section 2, we review the related research. In Section 3 we describe the setting, assumptions, and methodology of our market model. After calibrating the model in Section 4, we discuss numerical results for each support scheme in Section 5; these are followed in Section 6 by policy implications and sensitivity results. Section 7 concludes and points to future research directions.

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[1] Measured as the total cost of electricity supply.
[2] Also known as "security" of supply.

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2. Theoretical background

Our work builds on three different streams of research: assessments of RES support schemes, single-project electricity generation investment models, and generation capacity investment market models in the electricity sector. The first of these streams comprises both qualitative discussions and quantitative empirical ex post analyses of how RES support schemes affect investment in renewable energy sources; however, those analyses do not quantify the future impact of such schemes. The second foundational research stream investigates and quantifies investment in electricity markets under support schemes; similarly, it fails to account for future market effects. The third research stream is that dedicated to market models, which explicitly incorporate and focus on these market effects. So far as we can tell, however, no market model has been applied to conducting a rigorous numerical comparison of the various RES support schemes.

2.1. RES support schemes

Klein, Held, Ragwitz, Resch, and Faber (2007), Butler and Neuhoff (2008), and REN21 (2013) each review the different RES support schemes in place, and (Haas et al., 2004) survey the policies employed in European countries. These papers argue that FIT is the preferred mechanism for promoting RES investments.[3] In their comparison of RES support schemes in Germany and the United Kingdom, Butler and Neuhoff (2008) finds that FITs are significantly more effective in promoting the deployment of RES than are the UK's "Renewables Obligation Certificates". Along these lines, Ragwitz et al. (2006) demonstrate empirically that FITs have the greatest effect on RES investment and that countries relying solely on RPS schemes exhibit both low rates of buildup and high costs. More recent is the qualitative examination by Mormann (2012) of different RES support schemes, which concludes that – among these schemes – FITs have "the greatest conceptual capacity to leverage investment in the deployment of renewable energy technologies" (p. 734).

Mendonça, Jacobs, and Sovacool (2009) and Couture and Gagnon (2010) summarize the research on FIT schemes and provide an overview of FIT design options. Kim and Lee (2012) investigate different FIT payment structures, such as fixed and premium FITs; these authors report that the optimal FIT payment structure depends on policy objectives and expected future electricity prices. Shrimali and Baker (2012) find that FIT policies should be front- or back-loaded according as whether technology costs follow a "learning by doing" or rather an "economies of scale" dynamic. Lesser and Su (2008) emphasize the increasing pressure on governments for a drastic revision of extant FIT schemes. Research on MP is still limited and often is combined with FIT research. After comparing various FIT design options, Couture, Cory, Kreycik, and Williams (2010) conclude that a fixed and market-independent FIT scheme can increase investment security and lower the cost of capital, thereby attracting a diverse set of investors. That being said, a market-dependent and premium-price FIT scheme can increase market integration of RES capacity.

There is also abundant research on renewable portfolio standards, although most work focuses on the United States because RPS policies apply to nearly half of the US electricity load (Chen, Wiser, Mills, & Bolinger, 2009). These authors also find that, overall, only moderate retail rate increases should be expected after the introduction of RPS. Yin and Powers (2010) conduct an empirical study of RPS schemes and find that they have a significantly positive effect on in-state RES investment. Several studies have investigated the RPS policies of a particular US state (e.g., Illinois; see Johnson and Moyer, 2012). Most of this research concludes that such policies may fail to achieve their RES buildup objectives because regulators often pursue multiple – and often contradictory – goals when implementing RPS policies. Siddiqui, Tanaka, and Chen (2016) explore the setting of RPS quotas and find that, under perfect competition, the market could suffer from too much investment in renewable energy sources.

In short: although the existing literature on RES support schemes indicates that FITs are the most effective to increase RES investment, only a few studies have described effects beyond the RES buildup itself and the resulting short-term price changes.

2.2. Single project electricity generation investment models

A number of studies have assessed RES investment at the level of a single investor while also accounting (in part) for RES support schemes. Fleten, Maribu, and Wangensteen (2007) investigate optimal investment strategies under uncertainty. These authors apply the concept of real options and find that, if prices are volatile, then it is optimal to defer investment and wait for higher price levels. Kumbaroğlu, Madlener, and Demirel (2008) investigate the diffusion of RES when there are "learning curve" effects; they conclude that the high cost of RES means that support schemes are required to promote its diffusion in a liberalized market. Boomsma, Meade, and Fleten (2012) compare the impact of different RES support schemes and find that investment occurs earlier under a fixed FIT scheme but that larger projects are realized under a renewable energy certificate (REC)-based scheme. Ritzenhofen and Spinler (2013) also employ a real options framework and underscore the importance of regulatory uncertainty to any assessment of RES support schemes. Yet in all of this cited research, market conditions are assumed to be fixed and thus they do not account for market feedback or for competition among technologies. Hence it is necessary to extend these approaches in order to develop our understanding of the structural impact of RPS, FIT, and MP schemes on electricity markets. For that purpose, models of single-project energy investment are insufficient.

2.3. Generation capacity expansion models

One way to assess RES support schemes is by creating a dynamic generation capacity investment model representing an electricity market. Electricity market models have a long history and feature a variety of design options including long-term capacity expansion, short-term unit commitment, and/or dispatch models. Such models typically account for capacity planning but not for market price formation or customer reactions (Hobbs, 1995). Many of the traditional generation capacity expansion models seek to minimize the total cost of electricity generation by using linear programs (e.g., Fishbone and Abilock, 1981 or Bloom, 1983) or dynamic programs (Petersen, 1973). Models applied in the context of RES support schemes include those proposed by Jensen and Skytte (2002) and Fischer and Newell (2008). These models show that the effect of RPS schemes is strongly dependent on relative price sensitivities – in the electricity market and in the REC market – and additionally on the relative elasticities of electricity supply from fossil and renewable energy sources.

We extend these works by undertaking a more detailed analysis that is closer in spirit to Bistline (2012), Eager, Hobbs, and Bialek (2012b), and Fagiani, Barquín, and Hakvoort (2013). Eager et al. (2012b) employ a "representative agent" approach in their Monte Carlo simulation designed to assess conventional capacity investment in Great Britain for exogenously given levels of RES penetration. They forecast future electricity prices over a seven-year

[3] This preference is evidently (though not explicitly) based on the effectiveness – not the efficiency – of RES support schemes.