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Modeling and analysis of renewable energy obligations and technology bandings in the UK electricity market

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HIGHLIGHTS

- We model and analyze three renewable obligation policies in a mathematical framework.
- We provide revenue adequate pricing schemes for the three policies.
- We carry out a simulation study via sampling.
- The UK policy cannot guarantee that the original obligation target is met.
- Cost reductions can lead to more pollution or higher prices under banding policies.

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ABSTRACT

In the UK electricity market, generators are obliged to produce part of their electricity with renewable energy resources in accordance with the Renewable Obligation Order. Since 2009 technology banding has been added, meaning that different technologies are rewarded with a different number of certificates. We analyze these two different renewable obligation policies in a mathematical representation of an electricity market with random availabilities of renewable generation outputs and random electricity demand. We also present another, alternative, banding policy. We provide revenue adequate pricing schemes for the three obligation policies. We carry out a simulation study via sampling. A key finding is that the UK banding policy cannot guarantee that the original obligation target is met, hence potentially resulting in more pollution. Our alternative provides a way to make sure that the target is met while supporting less established technologies, but it comes with a significantly higher consumer price. Furthermore, as an undesirable side effect, we observe that a cost reduction in a technology with a high banding (namely offshore wind) leads to more CO_2 emissions under the UK banding policy and to higher consumer prices under the alternative banding policy.

1. Introduction

In decentralized electricity markets, firms are mainly focused on maximizing their profits while competing with other firms. Investments in cheap and often polluting technologies tend to serve these goals well. This is in conflict with the goals set by governments as they aim at reducing pollution and want therefore to create financial incentives to make investments in cleaner technologies more attractive. One way of creating these incentives is by means of a renewable energy obligation. This is a target on the proportion of electricity that should come from renewable resources and is imposed on one group of operators in the market. In several US states and in European countries like Belgium, Poland, Romania, Sweden, Italy, and UK, a renewable obligation is in effect.[1] The so-called green certificates are used to show compliance to the target, and typically one such certificate represents 1 MWh of renewable electricity production. At the end of each obligation period, often a year, each seller or producer should submit a certain number of certificates to the regulator. When not satisfying the target, typically a buy-out fine has to be paid.

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[1] For overviews of different support mechanisms across Europe, see Fouquet and Johansson (2008) and Koster et al. (2011).

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The latter comes with an opportunity cost that puts a value on each certificate, which forms the price that a seller is willing to pay to a renewable generator. The reward that generators receive adds to the short-term profits in a way that high long-term investment costs can be covered. Certificates can also be traded on a secondary market and as a consequence the renewable obligation does not oblige individual generators to produce a certain part of their electricity generation with renewable resources.

The UK and Italy form an exception to the system where one certificate represents 1 MWh of renewable electricity. In these countries certificates are banded according to technology, meaning that for different (renewable) technologies a different number of certificates is handed out per MWh of production. These so-called banding systems in the UK[2] and Italy[3] can help in encouraging investments in less developed technologies as to make them more competitive in the long run. This way it can overcome one of the shortcomings of the regular renewable obligation which is known to single out the most developed technologies, namely onshore wind power and to a lesser extent landfill gas (see Meyer, 2003; Wood and Dow, 2011; Verbruggen and Lauber, 2012). Although these technologies may be financially attractive, due to all kinds of geographical constraints and opposition against onshore wind farms, it is unlikely that the renewable obligation target can be met in the long run without investments in other renewable technologies like offshore wind, as emphasized by Toke (2011) and Wood and Dow (2011). As technology banding may result in a discrepancy between the total MWh of renewable electricity produced and the total number of certificates, in the UK the obligation shifted from one on renewable production to one on certificates. In the Italian system however, the regulator buys excess certificates.

We investigate the effects and side effects of both a standard renewable energy obligation and the UK banding system, using a mathematical model of the electricity market. In addition, we introduce an alternative banding policy in which the obligation is on renewable production and where certificate prices are modified to deal with the discrepancy between production and certificates. We model these three policies in a mathematical framework, by extending the stochastic version of the two stage investment model of the electricity market as introduced in Gürkan et al. (2013). In the model, investments are considered as long-term decisions (for example yearly) which take place at the first stage. Production, transmission, and market clearing are short-term decisions (for example hourly or daily) that take place in the spot market, referred to as the second stage. At the second stage, both demand and availability of renewable production capacity are subject to uncertainty. We assume perfect competition at both stages meaning that firms are price takers.

In order to make our model a good representation of reality and to keep results analytically tractable, we will make two simplifying assumptions with respect to the UK system. First of all, in the UK the renewable obligation is imposed on total electricity sales. We assume though that the firms producing power are selling their power directly to consumers, meaning that the obligation will be on electricity production. The second simplifying assumption concerns the trading of certificates. In reality, certificates can be traded daily on a secondary market and will have a certain value determined by the short term demand for certificates. Trading would be done on a daily basis and result in day-to-day variations in the value of a certificate. We overlook the micro details of the secondary trading market and therefore ignore the daily trading possibilities. Instead, we consider the average certificate value that holds over the year, which is directly related to the yearly obligation target. This average value is the reward that the regulator pays firms per certificate.

Typically, regulators strive for a certificate system to be revenue adequate, meaning that the system is self-financing without any loss or gain for the regulator. Therefore, for each policy we propose a way to price certificates and to adjust consumer prices such that the regulator's expenses on certificate payments are covered by mark-ups that consumers pay on top of the electricity price.

The three obligation policies are analyzed in a numerical study. We consider a market with two non-renewable technologies (coal and combined cycle gas turbine (CCGT)) and three renewable technologies (onshore wind (ONW), offshore wind (OFFW), and landfill gas (LFG)) and obtain investment quantities, prices, and CO_2 emissions for all three policies. A key observation is that in each policy, CO_2 emissions are curbed both by the increased renewable capacity and by the replacement of coal by the cleaner CCGT. Comparing the original obligation with the banding policies, we find that technology banding fails to create the right incentives for the less established OFFW when the obligation target is set too low. On the other hand, somewhat as a surprise, once OFFW is in the technology mixture, the UK banding system may result in higher levels of CO_2 emissions than the other systems. The alternative banding system proposes a possible solution for this undesirable side effect, albeit with relatively higher and less stable consumer prices.

Finally we analyze the effect of a decrease in the investment cost of OFFW. This leads to increased levels of CO_2 emissions in the UK banding system and increased consumer prices in the alternative system. These are obviously negative side effects of banding systems, implying that as costs reduce, financial support and hence bandings should be reduced accordingly.

This paper is organized as follows. In Section 2 we present the electricity market investment model, and subsequently propose modifications that account for the renewable obligation, the UK banding system, and an alternative banding system. For each system, we present a self-financing pricing scheme. The numerical methods and experimental data used for obtaining numerical results are presented in Section 3. Results are discussed in Section 4. Section 5 concludes and summarizes the policy implications.

2. The mathematical framework

2.1. The electricity market

We first provide a brief description of the electricity market. Given is an electricity grid with supply nodes at which firms owning generation plants produce electricity using their technologies that are renewable or non-renewable, and demand nodes at which consumers with, by assumption, inelastic random demand are located. Consumer demand is subject to uncertainty, caused by for example seasonality and daily changes in weather patterns. The output of renewable power plants may also vary from day to day and hour to hour. For example wind turbines are depending on daily weather conditions and influenced by the actual wind speed. A unit investment in wind energy does not mean that we can produce a given amount of power at all times. We refer to this uncertainty as the uncertainty in availability of capacity.

Firms make decisions in two stages. At the first stage all firms simultaneously maximize their profits while determining their optimal production capacity. Investment decisions can be seen as long-term decisions that are made once in every year. First stage profits of firms are dependent on the expected equilibrium outcome at the second stage, which in return is dependent on the investment decisions of all firms at the first stage. At the first

[2] For a description of the UK (banding) system, see Constable and Barfoot (2008) and Clark (2008).

[3] For a description of the Italian system, see Giovannetti (2009).