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Hydro resource management, risk aversion and equilibrium in an incomplete electricity market setting

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ABSTRACT

Since the outset of power system reform, one of the main objectives of regulation has been to assess whether the market, of its own accord, can induce agents to adopt decisions that maximise social welfare.
This paper analyses the effect of generating companies' risk aversion on their medium-term (typically 1 year) hydroelectric resource planning, along with its possible inducement of system operation that deviates from the centralised (maximum social welfare) solution.
Forward markets may play a key role by making hedging instruments available to risk-averse agents. A stylised mathematical model is used in this study to prove the equivalence of centralised planning and market equilibrium in the presence of such agents under the following assumptions: 1) both the spot and forward markets are perfectly competitive; 2) it has at least one risk-neutral consumer or arbitrageur; 3) all agents share the same beliefs about uncertain parameters; 4) only one price is in place in each trading period (which can be perfectly hedged with a forward contract); and 5) a solution for the resulting market equilibrium problem exists.
The findings show that such equivalence vanishes when forward markets are missing or inaccessible (attributable in some electricity markets to the absence of demand-side participation). This article consequently suggests that requiring demand-side agents to sign forward contracts with generators might constitute an effective regulatory measure where no fully functional forward market is already in place.

1. Introduction

1.1. Free markets and efficiency

Since the outset of power system reform, one of the main objectives of regulation has been to assess whether the market, of its own accord, can induce agents to adopt decisions that maximise social welfare. Where they deem that this may not be the case, but rather that the market deviates significantly from the social optimum, regulators may contemplate introducing mechanisms that would guide the market toward such an ideal. Real-time (in the US) and balancing (in the EU) markets, as well as other types of reserve markets run by system operators, are good examples of regulatory measures that aim to remedy market agents' potential inability to guarantee very short-term system security. Another obvious example of such measures, capacity mechanisms (Batlle and Rodilla, 2010) designed to guarantee long-term system adequacy, have been implemented since the advent of the market in North and South America (Batlle et al., 2015). Their institution in Europe is now being debated in depth (EU Commission, 2012, 2013).

The consensus opinion around the adoption of regulatory measures in general is that it should be preceded by accurate problem identification to be able to effectively tackle the specific market failure at issue (the actual ailment).[1] Market failures (including non-participation by agents or externalities) and how to deal with them in the short[2] (security) and very long[3] (adequacy) terms have long been debated. The medium-term dimension of the problem, and more specifically efficient medium-term resource management of existing facilities, have received scant attention in the academic literature, however.

1.2. The medium-term dimension of the problem

The medium term is typically defined to mean a 1-year period. Generators must manage their fuel stocks and hydro reserves in this

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[1] Insofar as regulation is not perfect, before intervening, regulators should ensure that any harm that might be caused by introducing an "imperfect mechanism" does not outweigh the potential benefits.
[2] See for instance Batlle et al. (2007) and Vandezande et al. (2009).
[3] See for instance Hogan (2005), Joskow (2007) and Pérez-Arriaga and Linares (2008).

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time frame and establish optimal generating unit maintenance schedules. Such medium-term decisions largely condition economically efficient dispatching given, for instance, their direct impact on the availability of resources when most needed. In electricity markets, these medium-term decisions are driven exclusively by market signals.

The importance of satisfactory medium-term resource management has been indirectly acknowledged in the practical regulation of electricity systems worldwide. Many regulatory mechanisms geared to enhancing adequacy (to attract new capacity) also include powerful incentives for both new and existing generators to increase their availability in the medium term, particularly in the presence of system scarcity. The penalties for non-compliance explicitly laid down in New England forward capacity market contracts are a case in point (see Batlle and Rodilla, 2010). This issue has become increasingly relevant with the growing penetration of variable energy resources such as wind and PV solar facilities.

1.3. Hydro resource management and risk aversion

Of the various types of medium-term resource management involved in electric power generation, the focus here is on hydro reserves. In light of their flexible implementation, efficiently managed hydro resources can be used to deal effectively with potentially high prices, particularly in many of today's markets where the deployment of intermittent generation technologies is growing fast.

The complexity involved in the operation of real hydroelectric systems[4] is simplified in the stylised formulation of hydro generation used here for readier calculation and subsequent interpretation of the optimality conditions. More specifically, the hydro system is modelled as an energy-constrained resource in which a certain amount of available energy has to be allocated over time, irrespective of inflow chronology during the year, limits to power output or non-linear dependencies.

The uncertainty around inflows and the many constraints on reservoirs render management of this resource and its inherent risks particularly complex. More specifically, the efficiency of medium-term resource management, which is associated with risk management, may be affected by a significant market failure, namely medium- and long-term electricity market incompleteness, as described below.

This paper analyses the combined effect of risk aversion among hydro (or hydro-thermal) generators and their inability to efficiently hedge medium- to long-term positions and shows that it may compromise efficient medium-term resource management.[5] In other words, incomplete markets are found to be able to steer hydro resource management away from the optimisation of social welfare. Assuming that market prices reflect true marginal costs, the study also shows that the model delivers the same solution for central planning, i.e., maximisation of expected social welfare, as for market equilibrium when the participants are risk neutral. When generators with hydro capacity are risk averse, however, they may use that capacity to hedge their exposure to risk, inducing dispatching that deviates from the maximum social welfare solution.

A number of analyses have been published on the effect of risk aversion on hydro resource planning by generating companies: see, for instance, Unger (2002) and Fleten et al. (2002). The scope of those analyses is enlarged here to include the social consequences of risk-averse behaviour and the respective regulatory implications.

1.4. Incomplete markets

Long-term financial markets are categorised in the literature as complete or incomplete (Duffie & Rahi, 1995). Long-term markets are defined to be incomplete when perfect inter-agent risk transfer does not take place. One of the major causes of that obstruction is what is known as the missing market problem. This situation and its consequences for electricity markets have been analysed in connection with efficiency in several contexts, including regional markets (Smeers, 2004a, 2004b) and long-term investment (Willems and Morbee, 2010).

The latter authors noted that the first and foremost conclusion drawn from the literature on the effects of the pricing of additional assets is that welfare is lower in incomplete than complete markets because risk is imperfectly allocated in the former.[6] That is the effect analysed here in the context of medium-term hydro planning.

1.5. Risk, equilibrium models and incomplete markets

Most equilibrium models that incorporate risk and long-term contracts are designed for long-term investment decision-making. As a general rule, the conclusions drawn from such models is that in the absence of long-term markets, agents' decisions differ from the ones they would have adopted if they were risk neutral. In this vein, the impact of uncertain CO_2 permit policies (Fan et al., 2009) and price uncertainty (Ehrenmann & Smeers, 2011) have been shown to have an impact that may call for compensatory regulatory measures.

Electricity market volatility is known to constitute an incentive for risk-averse producers and consumers to hedge their exposure to electricity prices by buying and selling derivatives. Studies have been conducted in which long-term contracting is built into the models to calculate equilibrium when risk-averse agents can hedge their risk. The overall conclusion is that investment in power plants rises under such circumstances because the more effective hedging afforded by additional derivatives makes them more appealing to investors. Willems and Morbee (2010) addresses this issue in some depth.

Other studies analyse the effects on welfare of including long-term contracting in equilibrium calculations. Research by Willems and Morbee (2010) showed that when forward contracting was introduced in the model, aggregate social welfare (calculated as the sum of individual firms' utilities) rose with the number of options (which generated a more complete market).

To the best of the present authors' knowledge, no prior equilibrium model studies have been conducted on the effects of risk aversion on medium-term hydro resource management. The findings of the present study of such effects are wholly in line with the earlier long-term approaches cited above.

1.6. Objectives and roadmap

The present theoretical analysis addresses hydro resource management in a context characterised by (i) perfect competition, (ii) risk-averse agents and (iii) incomplete long-term markets. It explores the impact of incomplete long-term markets, which translate into less socially efficient hydro resource management. Two scenarios are envisaged in the study: (i) a market where no financial instruments are available to generators, and (ii) a market where forward contracts

[4] Actual hydro system planning and operation are subject to many constraints that span all the decision variables involved. In cascaded multi-reservoir systems, account must be taken of the time- and space-related links that interconnect all the hydro plants operating on the same river basin. Natural inflows at hydro network nodes and losses due to evaporation or seepage must also be carefully modelled. Inflow chronology is one of the main sources of uncertainty. Further complexity is introduced by the non-linear dependence among net head, water flow and power output, along with other constraints such as water rights for consumption or irrigation. See Labadie (2004) for a comprehensive review of the state-of-the-art optimisation of reservoir system management and operations.

[5] As a general rule, incomplete markets are not Pareto efficient (see for instance Magill and Quinzii, 2002).

[6] Market completion does not necessarily benefit all agents. Complete markets are Pareto efficient, but not necessarily Pareto dominant with respect to all possible incomplete market allocations.