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An options pricing approach to ramping rate restrictions at hydro power plants ☆

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ABSTRACT

This paper investigates the impact of ramping rate restrictions imposed on hydro operations to protect aquatic ecosystems. The optimal ramping decision is specified as an optimal control problem which results in a Hamilton Jacobi Bellman (HJB) equation. Electricity prices are modelled as a regime switching stochastic process. The optimal control is determined by solving the HJB equation numerically using a fully implicit finite difference approach with semi-Lagrangian time stepping. The paper focuses on the effect of ramping restrictions on a hydro plant's value and optimal operations, and provides an analysis of which factors cause ramping restrictions to have a greater or lesser impact on profitability. It is shown that hydro plant value is negatively affected by ramping restrictions, but the extent of the impact depends on key parameters which determine the desirability of frequent changes in water release rates. Interestingly for the case considered, value is not sensitive to ramping restrictions over a large range of restrictions. The results point to the importance of accurately modelling electricity prices in gauging the trade offs involved in imposing restrictions on hydro operators which may hinder their ability to respond to volatile electricity prices and meet peak demands.

1. Introduction

Hydro electricity is considered an environmentally friendly source of power as it is not associated with the release of carbon and other harmful emissions. Water release rates can be easily adjusted in response to changing electricity demand and prices, making hydro a low cost option for meeting peak demands. However this operating flexibility is known to have environmental costs. As discussed in Edwards et al. (1999), frequent changes in water levels and changing release rates through turbines can alter water temperatures and change the chemical and physical composition of the released water which puts stress on aquatic flora and fauna. There may also be negative effects on beaches and increased erosion of

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shorelines which is detrimental to the natural balance of the local ecosystem.[1] The extent of these negative environmental impacts is case specific, depending on the size of the particular hydro operation and the fragility of the surrounding ecosystem, including the characteristics of the water body that receives the released water.

Regulators charged with protecting local ecosystems must consider the consequences of hydro operations for native flora and fish habitat.[2] Restrictions may be imposed on minimum and maximum water levels in reservoirs and rivers, release rates from reservoirs, and the rate of change in the release rate (ramping rate). Any restrictions on hydro operations must be considered in light of the impact on profitability for the hydro operator and on the capability of the electricity grid to meet peak demands. If there is greater reliance on fossil fuels for peaking requirements, there would be added environmental consequences resulting from the harmful emissions from coal, natural gas and petroleum.[3] The optimal choice of restrictions represents a complex problem which balances the consequences for the ecosystem with the lost profits to hydro operators and the possible impact on the electricity grid.

This paper addresses one aspect of this economic problem: the consequences for hydro operators of the imposition of ramping restrictions. The paper provides an analysis of the optimal response of hydro operators to ramping restrictions and of which factors cause ramping rate restrictions to have a more or less significant impact on profits. Knowledge of the costs of ramping restrictions to hydro operations can help illuminate trade offs and inform the design of regulations.

Hydro operators seeking to maximize profits face a complex dynamic optimization problem. The production of electricity depends in a non-linear fashion on the speed of water released through turbines as well as on the reservoir head, which refers to the height of the water in the reservoir. Releasing water at any given hour reduces the head and hence negatively affects the amount of power that can be produced in the next hour. Eventually the released water will be recovered through water inflow into the reservoir. Maximizing profits over time is thus a balancing act between water inflow to and outflow from the reservoir while responding to changing electricity demands over time and meeting regulatory restrictions.

Further complicating the decision problem is the complex nature of electricity prices. Electricity demand tends to follow a marked daily pattern, peaking during the daytime and early evening hours. It is also subject to seasonal spikes to meet demand for air conditioning in the summer and/or heating in the winter. Electricity has only very limited storage possibilities and the typical base load power sources, including coal and nuclear, are much more limited than hydro in their ability to vary generation levels. This results in fairly inelastic supply and consequent volatile electricity prices, particularly in those regions which rely heavily on fossil fuel and nuclear power. Price spikes and jumps are not uncommon.

The past decade has witnessed some significant changes in electricity markets as the mix of power sources has responded to government policies to reduce carbon emissions. In European electricity markets there has been strong growth in generation from solar and wind energy. These are intermittent power sources which are thought to further increase price volatility (Ziel et al., 2015; Clò and D'Adamo, 2015; Clò et al., 2015; Ketterer, 2014). Hydro operators can benefit from this volatility by increasing water release rates (ramping up) in response to high prices and by reducing water release rates (ramping down) in periods of low prices to let water levels recover in the reservoir.

Intuitively, ramping restrictions should have the largest impact on profits of hydro operations for which the optimal control without restrictions involves frequent ramping up or down of water release rates. This would be expected in an environment of frequently changing prices in which hydro operators are motivated to adjust water release rates accordingly. In an environment of uncertainty, with highly volatile prices, and/or multiple price regimes the ability to adjust water flows rapidly in response to price change provides a valuable option for a hydro plant owner. In order to exercise this option, water reserves in the dam must be managed accordingly. For example, in order to respond to sudden jumps in price, there must be adequate water levels so that power production can be rapidly increased. This contrasts with a scenario of stable or predictable price changes, when hydro operators can accurately anticipate future prices and prepare in advance to take optimal actions. In essence the storage provided by the hydro dam reservoir increases in value in an environment of highly uncertain prices.

In the current literature, there are relatively few studies of the costs and associated benefits of restricting ramping rates at hydro power plants. Early work on the economics of ramping restrictions includes Veselka et al. (1995), Edwards et al. (1999), Harpman (1999) and Edwards (2003), who examine the effect of particular ramping rate regimes as environmental constraints, but do not provide extensive analysis of ramping rate restrictions on the power station's optimal operation and value. The trade offs involved in the choice of the optimal ramping rate regime are not addressed in these papers. In a recent study, Niu and Insley (2013) extend these works by considering both the associated benefits and costs of ramping restrictions on hydro profits and on total daily hydro production and the potential implications for other sources of power. A limitation of the studies cited in this paragraph is that the optimization models are solved in a deterministic framework.

Uncertain electricity prices as well as water inflows imply that optimal hydro power operation is best studied in a stochastic framework. Thompson et al. (2004) and Chen and Forsyth (2008) study the hydro operation and valuation problem in a stochastic optimal control framework using jump diffusion models for electricity prices. Chen and Forsyth

[1] There is a consensus that modified water flows are affecting fish and fish habitat, but the response varies widely. See Murchie et al. (2008) and Marty et al., (2009) and references in Niu and Insley (2013).

[2] This is an issue that has received attention in numerous jurisdictions across North America. Smokorowski et al. (2009) discuss this issue in relation to the experience in Ontario. Some examples of hydro dams that operate with ramping constraints include the Glen Canyon Dams in Arizona (Veselka et al., 1995 and Harpman, 1999), the Sugar Lake Dam in British Columbia (BC Hydro, 2005), and the Kerr Dam in Montana (Flathead Lakers, 2005).

[3] This issue is addressed in Niu and Insley (2013) in a model of optimal hydro production with deterministic prices.