Energy Economics 61 (2017) 340–350

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

Low natural gas prices and the financial cost of ramp rate restrictions at hydroelectric dams

Jordan D. Kern [a,*], Gregory W. Characklis [a,b]

[a] University of North Carolina at Chapel Hill, Institute for the Environment, 100 Europa Drive, Suite 490, Chapel Hill, NC 27517-1105, United States

[b] University of North Carolina at Chapel Hill, Department of Environmental Sciences and Engineering, Rosenau Hall, Chapel Hill, NC 27599, United States

A R T I C L E I N F O

Article history:
Received 22 November 2015
Received in revised form 28 November 2016
Accepted 3 December 2016
Available online 8 December 2016

JEL classification:
L93
Q41
Q25
Q57
C63
G22

Keywords:
Natural gas prices
Electricity markets
Hydroelectric dams
Environmental impacts
Financial risk management

A B S T R A C T

Peaking hydroelectric dams that employ variable, stop-start reservoir releases can have adverse impacts on downstream river ecosystems. Efforts to mitigate these impacts have relied predominantly on the use of ramp rate restrictions, which limit the magnitude of hour-to-hour changes in reservoir discharge. Ramp rate restrictions shift hydropower production towards less valuable off-peak hours, imposing a financial penalty on dam owners that is a function of the "spread" (difference) between peak and off-peak electricity prices. This study examines how low natural gas prices in the U.S. have reduced the cost of implementing ramp rate restrictions at dams by narrowing the peak/off-peak price spread. Significantly lower costs of ramp rate restrictions could open new opportunities for improving environmental flows at dams, including the "purchase" of more natural streamflow patterns by downstream stakeholders, a type of arrangement for which there is growing precedent. We also explore the role that uncertainty in the cost of ramp rate restrictions could play in precluding downstream stakeholders from forming these types of agreements with dam owners. Results suggest that financial "collar" contracts could mostly eliminate inter-annual variability in the net cost of restrictions and provide those purchasing more natural flows with greater certainty.

1. Introduction

Optimizing the financial value of hydropower projects relies heavily on the practice of hydropower "peaking," in which dams produce electricity (release water) at maximum rates during high demand hours and release much less water during other, less valuable hours. However, the large hourly fluctuations in river flows that occur as a result of this practice can cause significant environmental impacts downstream, including: habitat loss, altered physicochemical properties, changes in sediment dynamics, stranding of fish and other organisms, and/or the disruption of life cycle processes (Cushman, 1985; Blinn et al., 1995; Freeman et al., 2001; Grand et al., 2006; van Looy et al., 2007). In recent years, efforts in the U.S. to protect rivers from the effects of hydropower peaking have become more widespread, particularly through litigation and the Federal Energy Regulatory Commission's (FERC) dam relicensing process (DeShazo and Freeman, 2005). Jager and Bevelhimer (2007) found that of the 223 dams whose licenses were renewed between 1988 and 2000, 23 (10%) were converted from peaking to "run-of-river" operations, a distinction that means reservoir output is set equal to inflows on a daily and/or hourly basis. Nonetheless, the perceived high value of hydropower as a peaking resource persists as a barrier to restoring natural hourly variability in river flows at other dam sites.

Efforts to restore natural hourly variability in river flows below dams most commonly involve the use of "ramp rate" restrictions, or limits on the magnitude of hour-to-hour changes in reservoir discharge, which force a fraction of total hydropower production to be shifted away from periods of peak electricity demand towards less valuable off-peak hours. The financial penalty that dam owners incur as a result of these restrictions is a function of two factors: 1) the "spread" (difference) between peak and off-peak electricity prices; and 2) the total amount of generation that is shifted from peak to off-peak hours (this amount, in turn, depends on the availability of water for hydropower production) (Edwards et al., 1999; Harpman, 1999; Palmer et al., 2004; Kotchen et al., 2006).

A handful of studies have estimated the annualized financial cost of ramp rate restrictions at different dams in the U.S. and Canada (Harpman, 1999; Kotchen et al., 2006; Jager and Bevelhimer, 2007; Niu and Insley, 2013, 2016; Guisandez et al., 2013). However, with few exceptions (Guisandez et al., 2013; Niu and Insley, 2016) these

* Corresponding author.
E-mail address: jdkern@live.unc.edu (J.D. Kern).

http://dx.doi.org/10.1016/j.eneco.2016.12.002
0140-9883/

efforts give little consideration to the extent to which the cost of ramp rate restrictions at dams can vary on a year-to-year basis due to fluctuations in the peak/off-peak price spread and reservoir inflows. A more comprehensive understanding of how each of these factors drives changes in the cost of ramp rate restrictions would allow for improved forecasts of these costs to be included in real-time dam/river management, as well as longer-term dam relicensing discussions. Notably, none of these studies address a recent surge in US natural gas production that has important implications for the peak/off-peak price spread in electricity markets and the cost of ramp rate restrictions at dams.

In PJM Interconnection (a wholesale electricity market that covers much of the eastern U.S.) the two main drivers of the peak/off-peak price spread are electricity demand and the price of natural gas. Fig. 1 shows the typical system supply (marginal cost) curve for the PJM day-ahead market, estimated using 2010 EPA eGrid data (EPA, 2015). The system supply curve is broken down by fuel type (color); assumed fossil fuel prices are \$10/MMBtu for fuel oil, \$5.5/MMBtu for natural gas, and \$2/MMBtu for coal. Market (peak and off-peak) prices are determined by the intersection of vertical demand curves with the system supply curve.

Historically, the off-peak price of electricity in PJM has been relatively constant because it is associated with the marginal cost of using electricity from coal plants to meet relatively low demand. Coal prices have historically demonstrated little volatility, and the part of the supply curve associated with coal plants is flat, thus reducing the impacts that year-to-year fluctuations in demand have on off-peak prices. Major fluctuations in the peak/off-peak spread track the peak price of electricity, which is strongly associated with the marginal cost of electricity at natural gas power plants (EIA, 2013). Fig. 1 illustrates how fluctuations in the price of natural gas can alter the marginal cost of electricity at natural gas plants and, as a consequence, impact peak prices and the peak/off-peak price spread in the PJM market. Solid black lines indicate how the contour of the supply curve is changed by natural gas price increases/decreases of \$2.5/MMBtu. As the price of natural gas rises and falls, so do the peak price of electricity and the peak/off-peak spread.

In recent years, the combination of improved horizontal drilling techniques and hydraulic fracturing, or “fracking”, has led to a surge in domestic U.S. gas production and contributed to an extended period of

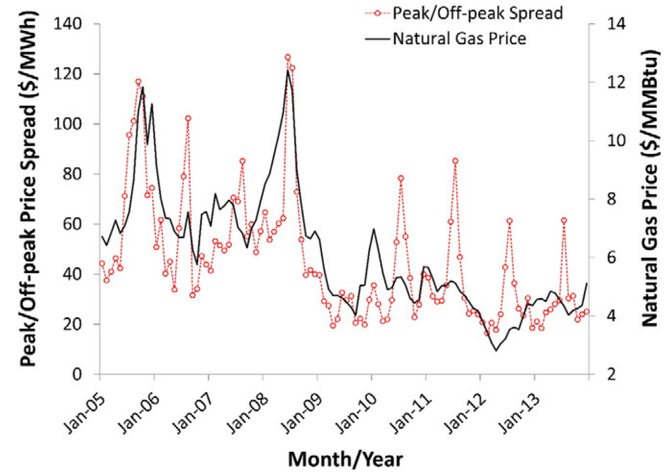

Fig. 2. Average monthly peak/off-peak electricity price spread in PJM Interconnection (black) and average delivered monthly natural gas prices for electric utilities over the years 2005–2013. The peak/off-peak price spread shows seasonality (increasing in summer and winter months) and a significant correlation with natural gas prices. Both average natural gas prices and peak/off-peak electricity show a step-change decrease in 2009 that persists through 2013.

low natural gas prices (McElroy and Lu, 2013). As a consequence, peak electricity prices and the peak/off peak price spread in PJM have declined, reaching a relative low point in 2012 (a year in which the US also experienced unseasonably mild weather and relatively low electricity demand) (Fig. 2) (NCDC, 2015). A major goal of this research is to determine the extent to which corresponding downward trends in the price of natural gas and the peak/off-peak price spread have reduced the cost of implementing ramp rate restrictions at hydroelectric dams.

If low natural gas prices persist over many years, it could open new, less expensive opportunities for improving environmental flows at dams. A number of previous studies have shown that consumers' willingness-to-pay for more environmentally friendly practices at hydroelectric dams depends on cost and the relative importance of

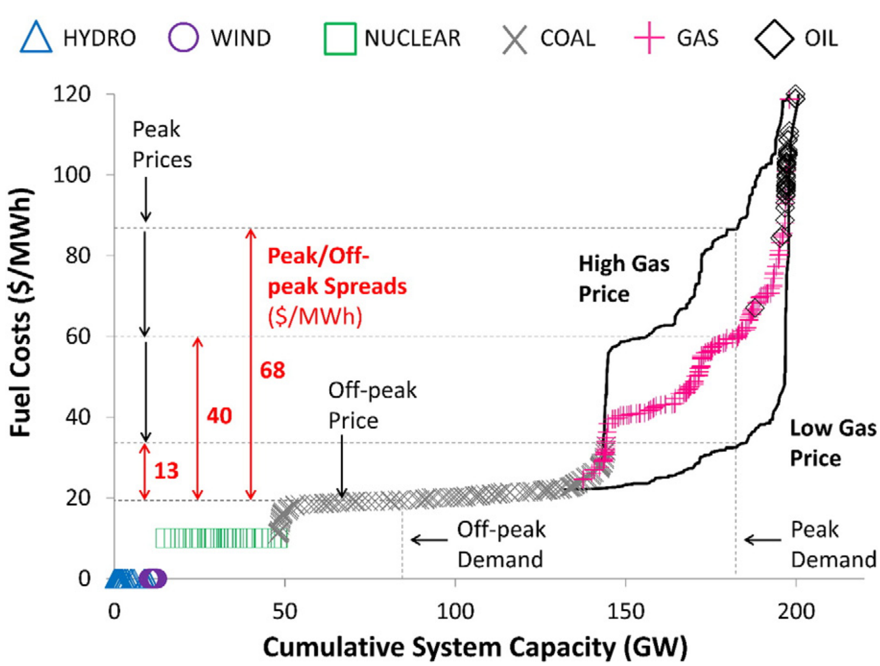

Fig. 1. Determination of peak/off-peak price spread in a wholesale electricity market. The peak/off-peak price spread increases and decreases with the price of natural gas. Market (peak and off-peak) prices are calculated as the intersection of vertical demand curves and the system supply (marginal cost) curve. The marginal cost curve was developed using EPA eGrid data for all generation resources within the PJM Interconnection footprint.