The Electricity Journal 31 (2018) 7–12

Contents lists available at ScienceDirect

The Electricity Journal

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

# An empirical analysis of California's hybrid capacity options

C.K. Woo[a,*], J. Zarnikau[b], Y. Chen[c], A. Olson[d], J. Moore[d], T. Ho[e], Y. Liu[a], X. Luo[a]

[a] Department of Asian and Policy Studies, Education University of Hong Kong, Hong Kong
[b] Department of Economics, University of Texas, Austin, TX 78713, USA
[c] Department of Technology Management, Jack Baskin School of Engineering, UC Santa Cruz, CA 95064, USA
[d] Energy and Environmental Economics, Inc. (E3), 101 Montgomery Street, Suite 1600, San Francisco, CA 94104, USA
[e] Flat H, 16/F, Block 3, Wing Fai Centre, Fanling, New Territories, Hong Kong

ARTICLE INFO

*Keywords:*
Hybrid capacity options
Market-based payoffs
Tradeoff among option attributes
California

ABSTRACT

We propose a new approach to analyze the payoffs of a hybrid capacity option with a daily-varying strike price. We document that the option's payoffs are less than the capacity payments required to attract customer participation. We also present results useful for designing payoff-neutral options to enhance customer participation in a capacityidding program. Our proposed approach is equally applicable for a transparent analysis of the payoffs of other types of exotic capacity options.

## 1. Introduction

To implement market competition, the electricity industry has been regionally restructured in various parts of Europe, North America, South America, Asia, Australia, and New Zealand (Sioshansi, 2013). Wholesale electricity trading and procurement have led to extensive research in electricity price behavior, derivatives, and risk management (Pilipovic, 1997; Eydeland and Wolyniec, 2003; Deng and Oren, 2006; Weron, 2006; Benth et al., 2008; Edoli et al., 2016).

This paper's goal is to estimate the monthly payoffs of a hybrid capacity (call) option that gives the buyer (e.g., a local distribution company, or LDC) the right, but not the obligation, to procure an amount of electricity from the seller (e.g., an owner of an aging combustion turbine) at the daily-varying specific strike price $S_t$ = contracted heat rate $HR$ (MMBtu/MWh) × daily natural gas price $G_t$, subject to the contracted terms of frequency $F$ = maximum number of calls (or events in the LDC's tariff description) per month and duration $D$ = daily maximum of hours per event. Exemplified by Pacific Gas and Electric Company's (PG&E's) capacity bidding program (CBP) described in Table 1, the option is a hybrid because it combines the daily-varying strike price $S_t$ of a tolling agreement (Woo et al., 2004a) and the $F$ and $D$ limits of a capacity call option with a fixed strike price (Lloyd et al., 2004).

Our estimation aims to answer the following questions:

- Is a hybrid option's monthly payoff sufficiently high to justify its procurement cost? This question's real-world relevance is underscored by PG&E's monthly capacity payments of up to $24.81/kW, as shown in Table 1. If the payoff is far below the payment, a cost-effectiveness assessment of the option needs to include additional system benefits related to reliability and renewable energy integration (Moore et al., 2010).
- How does a hybrid option's payoff move with $F$, $D$ and $HR$? The answer to this question helps refine the design of a CBP that is payoff-neutral. For example, an increase in $F$ accompanied by a decrease in $D$ may improve the CBP's attractiveness to some potential participants, while keeping the CBP's payoffs unchanged.

Based on the market data published by the California Independent System Operator (CAISO) for the 30 summer months of May to October in the 5-year period of 2011 to 2015, our two key findings are as follows. First, the option's payoffs are likely less than the capacity payments required to attract customer participation. This suggests that the option's cost-effectiveness should include other benefits attributable to relieving transmission and distribution constraints and integrating intermittent renewable generation. Second, our regression results demonstrate the tradeoffs among a hybrid option's attributes of frequency, duration, and heat rate. Such results are useful for designing payoff-neutral options to enhance customer participation in a CBP like PG&E's.

Our paper makes three contributions to the literature on the valuation of an *exotic* option (Deng et al., 2001; Lucia and Schwartz, 2002; Eydeland and Wolyniec, 2003; Burger et al., 2004; Deng and Oren, 2006; Benth and Koekebakker, 2008; Benth et al., 2008; Ryabchenko

* Corresponding author.
*E-mail addresses:* chiwoo@eduhk.hk (C.K. Woo), jayz@utexas.edu (J. Zarnikau), yihsuchen@ucsc.edu (Y. Chen), arne@ethree.com (A. Olson), jack@ethree.com (J. Moore), hstony1@outlook.com (T. Ho), yliu@eduhk.hk (Y. Liu), lxinpei@eduhk.hk (X. Luo).

https://doi.org/10.1016/j.tej.2018.02.005

**Table 1**
Features of PG&E's capacity bidding program.

| CAPACITY PRICE: | Capacity Price by Month<br>Aggregators in Day-Ahead Option | | | | | | |
|---|---|---|---|---|---|---|---|
| | Product | May | June | July | August | September | October |
| | 1–4 h | $3.04/kW | $3.71/kW | $15.60/kW | $21.57/kW | $13.30/kW | $2.17/kW |
| | 2–6 h | $3.04/kW | $3.71/kW | $15.60/kW | $21.57/kW | $13.30/kW | $2.17/kW |
| | 4–8 h | $3.04/kW | $3.71/kW | $15.60/kW | $21.57/kW | $13.30/kW | $2.17/kW |
| CAPACITY PRICE: | Capacity Price by Month<br>Aggregators in Day-Of Option | | | | | | |
| | Product | May | June | July | August | September | October |
| | 1–4 h | $3.50/kW | $4.27/kW | $17.94/kW | $24.81/kW | $15.30/kW | $2.50/kW |
| | 2–6 h | $3.50/kW | $4.27/kW | $17.94/kW | $24.81/kW | $15.30/kW | $2.50/kW |
| | 4–8 h | $3.50/kW | $4.27/kW | $17.94/kW | $24.81/kW | $15.30/kW | $2.50/kW |

| Day-Ahead Options | | | | |
|---|---|---|---|---|
| Product | Minimum Duration per Event | Maximum Duration per Event | Maximum Event Hours Per Operating Month | Maximum Events Per Day |
| 1–4 h | 1 h | 4 h | 30 | 1 |
| 2–6 h | 2 h | 6 h | 30 | 1 |
| 4–8 h | 4 h | 8 h | 30 | 1 |
| **Day-Of Options** | | | | |
| Product | Minimum Duration per Event | Maximum Duration per Event | Maximum Event Hours Per Operating Month | Maximum Events Per Day |
| 1–4 h | 1 h | 4 h | 30 | 1 |
| 2–6 h | 2 h | 6 h | 30 | 1 |
| 4–8 h | 4 h | 8 h | 30 | 1 |

Note: Both option types have advance notification: (a) day-ahead options: by 3:00 PM on a day-ahead basis for the next working weekday; (b) day-of options: 3 h ahead on a working weekday. All options have 30 as the maximum number of event hours per month. The capacity payment of a given option does not vary by duration.

and Uryasev, 2011; Edoli et al., 2016). First, when compared to stochastic process modeling and mathematical programming, our regression-based approach is computationally attractive, transparently determining a hybrid option's payoff. Second, our approach is general, applicable to other options such as a tolling agreement with monthly dispatch restrictions or a collar option with $F$ and $D$ contract terms. Finally, we use the California market data to demonstrate the approach's real-world application. This demonstration is useful to other regions with similar data availability, including Europe, Australia, New Zealand, the U.S. markets of New York, New England, PJM, and ERCOT (Texas), and the Canadian provinces of Alberta and Ontario.

We proceed as follows. Section 2 presents our methodology and materials. Section 3 reports our empirical results. Section 4 concludes.

## 2. Methodology and materials

### 2.1. The useful role of a capacity option

To provide a contextual background of our paper, we briefly review the useful role of a capacity option in an electric grid's resource planning and operation.

A capacity option helps address an electricity grid's capacity needs, as explained by Spinler and Huchzermeier (2006) for a capital-intensive industry with non-storable goods. It also facilitates efficient grid operation and risk management (Thompson, 2013).

It may financially sustain an aging combustion turbine (CT) that would otherwise be shut down due to its high per-MWh fuel cost or emissions constraints imposed by the local air quality standards. It may also induce an electricity prosumer with dispatchable generation to participate in capacity bidding (Sreedharan et al., 2016; Ottesen et al., 2016).

A capacity option's dispatch flexibility helps manage intermittent renewable generation (Farret and Simões, 2006; Lopes et al., 2007; Milligan et al., 2010; Denholm and Hand, 2011; Rajagopal et al., 2013; Cutter et al., 2014; Huber et al., 2014). It is also useful for resolving transmission congestion caused by major equipment failures and weather-related demand surges (Kumar et al., 2005; Woo et al., 2011b).

Along with other resource alternatives (e.g., generation plants, forward contracts, tolling agreements, and demand response), capacity options can be part of a LDC's optimal resource portfolio that entails the tradeoff between the LDC's cost expectation and risk exposure (Kleindorfer and Li, 2005; Woo et al., 2004b, 2006; Inderfurth et al., 2013; Ottesen et al., 2016).

Finally, capacity options complement curtailable/interruptible (C/I) load contracts that aim to (a) efficiently allocate an electric grid's limited capacity during a shortage (Chao and Wilson, 1987; Woo, 1990; Spulber, 1992; Wilson, 1993; Horowitz and Woo, 2006; Woo et al., 1998, 2008, 2014b) and (b) reliably integrate an increasing amount of intermittent renewable energy into an electric grid (Cappers et al., 2012; Aghaei and Alizadeh, 2013; Aghaei et al., 2016).

### 2.2. Why California?

Our paper's geographic focus reflects that California is the eighth-largest economy in the world and has readily available data to comprehensively estimate the relationship between a hybrid capacity option's payoffs and design parameters.

Despite its rocky start marked by the 2000–2001 crisis,[1] California's

[1] The details of the crisis are well documented: see Borenstein (2002), Jurewitz (2002), Joskow and Kahn (2002), Wolak, (2003), Woo (2001), Woo et al. (2003), and Sweeney (2013).