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Optimal LNG (liquefied natural gas) regasification scheduling for import terminals with storage

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ABSTRACT

We describe a stochastic dynamic programming model for maximising the revenue generated by regasification of LNG (liquefied natural gas) from storage tanks at importation terminals in relation to a natural gas spot market. We present three numerical resolution strategies: a posterior optimal strategy, a rolling intrinsic strategy and a full option strategy based on a least-squares Monte Carlo algorithm. We then compare model simulation results to the observed behaviour of three LNG importation terminals in the UK for the period April 2011 to April 2012, and find that there was low correlation between the observed regasification decisions of the operators and those suggested by the three simulated strategies. However, the actions suggested by the model simulations would have generated significantly higher revenues, suggesting that the facilities might have been operated sub-optimally. A further numerical experiment shows that increasing the storage and regasification capacities of a facility can significantly increase the achievable revenue, even without altering the amount of LNG received, by allowing operators more flexibility to defer regasification.

1. Introduction

LNG (liquefied natural gas) is becoming an increasingly important source of energy for many countries. In the United Kingdom – with an annual natural gas consumption of around 900 TWh and once a significant exporter of natural gas – imports of LNG by ship have exceeded national gas production since 2009 [15] . Other natural gas-dependent regions are also expected to follow the same pattern, with LNG imports by ship increasing as regional natural gas reserves are gradually depleted.

Natural gas consumption typically exhibits a seasonal pattern due to its use for heating, and changing meteorological conditions can cause large and rapid changes in consumption. Natural gas producers, however, have little flexibility to change their deliveries on short notice and for this reason the integrity and safety of the natural gas pipeline network depends heavily on storage facilities that have the ability to react quickly to demand changes. Storage facilities therefore constitute a critical part of the natural gas infrastructure.

LNG importation terminals normally contain an array of onshore storage tanks into which the incoming LNG cargoes are unloaded. The tanks serve primarily as a buffer storage to compensate between the bulk offloading of LNG from ships and the gradual flow of natural gas to customers. The LNG is stored in the tanks until it is regasified and delivered to customers through a pipeline network. The storage tanks share some characteristics with traditional gas storage facilities, most importantly they often have the ability to rapidly change their deliveries to the pipeline network and can thus contribute significantly to the integrity and safety of the natural gas pipeline network. Due to the rapid response offered by LNG storages, many pipeline operators have constructed separate LNG storage facilities specifically for emergency situations.

In the context of a deregulated market, storage operators are faced with the problem of scheduling their withdrawals from storage in order to maximise their profit. Assuming that the market

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price of the gas to some degree reflects the excess or scarcity of gas, the traditional storage players buy and store gas during periods of excess, then sell and discharge gas during periods of relative scarcity, profiting on the price differences between the periods. Incidentally, this profit-seeking behaviour also provides increased supply security and price stability ([6,15];). Operators of LNG storage tanks at importation terminals are faced with a similar optimisation problem as operators of traditional storages, although the operational characteristics and constraints of these facilities differ from traditional gas storage facilities. Therefore, this study focuses on the optimisation of withdrawals from these increasingly important facilities with their distinct characteristics.

Lai et al. [10] appear to be the first, and so far only, to specifically address the storage of LNG at importation terminals, although their model considers the storage component in the larger context of a full LNG value chain rather than in isolation. This treatment may be inappropriate in the case where the source of cargoes is not predetermined, for instance when individual cargoes are bought from various suppliers on shorter notice (e.g. "spot" cargoes). Furthermore, they find that the value of the real option to store LNG at a regasification terminal is largely insensitive to stochastic variability in the shipping process, which is an important result and implies that the model can be greatly simplified to consider only the storage component in isolation. In addition to isolating the modelling of LNG storage at the import terminal from the rest of the LNG value chain, we would also like to avoid the discretisation of the price process that is required by their model and is generally undesirable since natural gas spot prices tend to vary over a wide range.

Although there has been little research specifically on the optimisation of LNG storage tanks at import terminals, the problem is closely related to management of traditional natural gas storage facilities, such as depleted fields, aquifer and salt caverns. The management of these types of natural gas storage facilities has attracted significant research interest, mainly under the guise of gas storage valuation using real-option theory because modelling the optimal management is a necessary step for assessing the value of natural gas storage [13]. Weston and Ronn [19] recognised gas storage valuation as a stochastic dynamic programming problem and proposed a solution that requires a discretisation of the inventory and price, of which the latter is a somewhat problematic requirement that is avoided in this study. Drawing on similarities with hydrothermal scheduling, Bringedal [3] modelled the optimal operation of gas storage using the stochastic dynamic dual programming method developed by Pereira and Pinto [16]. Boogert and de Jong [2]; as well as Carmona and Ludkovski [4]; proposed least-squares Monte Carlo approaches based on the options valuation framework of Longstaff and Schwartz [11]. Chen and Forsyth [5] treat gas storage valuation as a stochastic control problem which results in a Hamilton–Jacobi–Bellman partial differential equation, and can be resolved numerically with a semi-Lagrangian discretisation method. Thompson et al. [18] also propose an approach based on the numerical resolution of non-linear partial differential equations, with a particular emphasis on capturing the parabolic and hyperbolic nature of the natural gas storage operating characteristics. Lai et al. [9] proposed an approximate dynamic programming method to value the real option of storing natural gas, and found that sequentially optimising a deterministic model of the intrinsic value could provide a near-optimal policy at reasonable computational cost.

We propose a stochastic dynamic programming model specifically for maximising the revenue of LNG storage tanks at importation terminals in relation to a spot market. Although the model is based on the model developed by Boogert and de Jong [2], it extends this approach to include additional constraints that are characteristic to this specific type of storage: most importantly the absence of storage injection and the arrival of bulk shipments of LNG. Then we perform numerical simulations for three LNG importation terminals in the United Kingdom—Isle of Grain, South Hook and Dragon — based on real-world data from April 2011 to April 2012. We investigate whether or not the simulations match the observed regasification decisions, in order to discover if the operators really are maximising their revenues and if the model can be useful for forecasting purposes. Furthermore, we conduct a numerical experiment with counterfactual parameters for one of the facilities to illustrate how model simulations can be used to estimate the additional revenue resulting from a hypothetical increase in storage and regasification capacities.

Our research mainly differs from earlier efforts in two ways. Firstly, we focus in isolation on LNG storage tanks at importation terminals, which are becoming increasingly important parts of the supply infrastructure in many regions and we incorporate constraints and characteristics specific for this type of storage. Such a treatment does not, to our knowledge, exist in the current literature. Secondly, no earlier study appears to have compared the behaviour of a natural gas or LNG storage optimisation model to the observed behaviour of facility operators, although this could provide some very interesting insights into both the validity of such models and the behaviour of operators in practice.

There are four groups who might take a particular interest in this study. Firstly, the model may help investors and engineers assess how various technical properties of a facility affect the economic value. Secondly, the model and the numerical simulation strategies may help operators of LNG storage tanks at importation terminals improve their regasification decisions and increase their revenue. Thirdly, given the market impacts of such decisions, participants in gas and adjacent markets (other regions as well as other commodities) may be interested since the results will reveal operational characteristics of important participants and may help improve forecasting capabilities. Finally, those with a practical interest in market efficiency and consumer benefits, such as regulators and government agencies, may be interested in evaluating to what extent the market mechanisms are successfully achieving certain objectives.

A mathematical specification of a revenue-maximising model for LNG storage tanks at importation terminals follows in the next section. In the third section, parameter calibration and three numerical simulation strategies are discussed. The fourth section discusses the results of numerical simulations carried out for three LNG importation terminals in the UK based on data from the period April 2011 to March 2012 and a hypothetical capacity expansion. The fifth section outlines the main conclusions of this study in brief.

2. A revenue-optimising model for scheduling regasification from LNG storage tanks at importation terminals

We assume that the operators of LNG storage tanks in the importation terminals daily select the quantity of gas to regasify, sell and discharge into the pipeline network in order to maximise their expected accumulated revenue over a given time horizon. In addition to the technical capacity restrictions of the facility, the available actions are constrained by the initial stock level, the schedule of arriving LNG cargoes and the prices for the natural gas offered in the spot market. This study intends to analyse only the operation of the LNG storage tanks, and for this reason the schedule for LNG deliveries by ship will be considered fixed and given. This model will also not consider the influence of the actions of the operators on the market prices, which will be considered exogenous to the model.

Assuming that the operators choose their daily deliveries at the start of each gas day and do not change their mind in the course of