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Invited review

# Gas storage valuation and optimization

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ABSTRACT

In this paper we review the pricing and optimization of natural gas storage in competitive natural gas markets. Over the past decade valuation approaches have been suggested. Of those approaches, the most general ones are based on Monte Carlo price simulations, allowing the evaluation of different market trading strategies and different assumptions about the underlying price process. In a simulation exercise we first demonstrate that the impact of parameter (e.g. volatility) uncertainty on storage value is relatively limited. Inevitably, different market parameters lead to different storage values, but the trading strategy is relatively robust for a reasonably wide range of market parameters. Parameter uncertainty is also evaluated in a large-scale backtest of different storage trading strategies. The backtest of three different virtual gas storage types in the UK market provides a unique insight in how spot optimization combined with forward hedging would have fared over the past 17 years. On average, the estimated storage value is realized with a combination of spot optimization and dynamic delta hedging in the forward market. Dynamic intrinsic hedging of the spot exposures works relatively well too, but less so than delta hedging.



## 1. Gas storage assets role in the gas value chain

Storage plays a vital role in competitive natural-gas markets, because the average variability in the consumption of natural gas is much greater than the average variability in production. Demand is not only fluctuating, but often also at a considerable distance from the production sources. In both North-America (US + Canada) and Europe (OECD countries) natural gas storage capacity measured by working volume is around 18% of total consumption (IEA, 2012). Flexibility in the gas supply is also provided by production variations, pipeline and LNG transportation, but gas storage takes a large share of flexibility in many demand areas. For example, the US natural gas production has sharply increased due to the shale gas revolution in the past 5–10 years. The locations of production were not always well connected to the traditional demand areas, which has boosted investments in both transportation and storage (IHS, 2013).

For both the optimal planning of investments and the operation of existing facilities, it is necessary to fully understand the value drivers of natural gas storage. This article provides a review of the gas storage valuation literature and the relevant issues concerning different methodologies. This is combined with a backtest analysis, which provides very insightful results about the actual ability to monetize the storage value in trading markets.

The insights from this article can be applied to both physical storage assets and to storage services. In any case, a gas storage (asset or product) has three main operating characteristics: working gas volume, withdrawal rate and injection rate. The working gas volume is the capacity which can be actively used in cycling the gas through the storage in several days, weeks or months. Another part of the storage volume, the cushion gas volume, is needed to maintain enough pressure, but is not used operationally; it may be a big portion of the initial investment though. The withdrawal or send-out rate defines the volume which can be withdrawn, often expressed per day or hour. It may be volume-dependent with lower rates when there is relatively little gas in the storage asset. Likewise, the send-out rate, the third primary storage parameter is often decreasing when the storage is almost full. Other important storage parameters are the variable costs for injection and withdrawal, the maintenance and support costs for operating the facility, and of course the location of the storage.

Natural gas storage assets have been constructed in different geological structures, which are often categorized in the following

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three groups: empty oil and gas fields, salt caverns and aquifers. Empty oil and gas fields generally provide the largest working volume, i.e. the volume which can effectively be used for making cycles of injection and withdrawal in a year. Albeit being large in working volume, the deliverability, measured by the withdrawal or send-out rate, is often comparatively low. This means that former oil and gas fields are mostly used for providing seasonal flexibility, having the ability to cycle once or at most twice a year. Aquifers and salt caverns tend to have smaller working volumes but (much) higher deliverability. The right mix of seasonal and high-cycle storage assets, in combination with other sources of supply flexibility, is important for demand areas to absorb fluctuations in natural gas demand in a variety of market conditions. The larger and slower storage assets help to bridge the demand differences between seasons, for example fill up in summer and deliver in winter (heating). In turn, high-cycle storage assets, often in combination with LNG storage tanks, provide quick short-term security of supply, needed during a series of cold winter days (heating) or hot summer days (air-conditioning creating high power demand).

In liberalized markets, the natural-gas storage service is unbundled from the production, sales and transportation services. This means that storage is offered as a distinct, separately charged service under different regulations of third-party access. When there is a sufficiently liquid market for spot and forward or futures trading, market players can adjust their trading and operating decisions to the price signals. This allows them to benefit from price spreads and price movements (volatility).

Market players tend to own or contract natural gas storage flexibility primarily for managing the fluctuations in their own portfolio. In areas with limited or no trading possibilities, storage capacity is inefficiently used, because every player has to secure sufficient flexibility in his own portfolio. Thanks to liberalization, market players may not have to find the perfect balancing within their own portfolio. They may be net short or long flexibility and make their ultimate operational decisions based on a combination of internal flexibility sources and market prices. This leads to a more efficient use of available capacities for the market as a whole. The ongoing liberalization process in the European markets, and the improved decision making processes within the energy companies, is therefore one of the explanations of the lower price volatility and lower winter–summer spreads, especially on the continental markets. This has gone hand in hand with larger trade volumes and lower profitability of storage assets. From the viewpoint of system security of supply this may be a dangerous equilibrium: under normal market conditions the available storage capacity is efficiently used and available at relatively low cost. However, over longer horizons and in unusual market conditions there may be a shortage of storage flexibility in the system. This is a general policy maker's concern in liberalized markets which require long-term investments. The perfect policy mechanism for dealing with such potential under investments does not exist and individual countries have adopted a variety of approaches, ranging from holding 'strategic' reserves to investment subsidies or obligations on supply companies to contract a minimum level of storage capacity. All such mechanisms may increase security of supply, but introduce other market inefficiencies, both in the operational use of capacities and in new investments (Chaton et al., 2008; Redpoint Energy, 2013).

In a situation of liquid gas markets, the value of gas storage can be primarily derived from market prices. It depends much less so on the individual portfolio of single players, since all players have the ability to trade in the common marketplace. The valuation approaches which we discuss in the next section all take a market oriented approach, and all rely on a specific underlying financial economic model. An important element in those models is the dynamics of the price process. We provide an analysis of model risk and parameter uncertainty in Section 3. The final main section discusses the backtest. The backtest is essentially a very practical review of storage valuation in which all the topics of previous sections are reviewed from a practical pricing and optimization perspective. In Section 5 we conclude.

## 2. Valuation approaches to gas storage

There are basically four valuation approaches to natural gas storage: intrinsic, rolling intrinsic, basket of spreads and spot trading (see e.g. Boogert and de Jong, 2011). We discuss each approach individually, starting with the intrinsic calculation. It takes the current forward curve, calculates the optimal trades in the forward market and the corresponding cash-flows. The search for the optimal trades in the forward market includes all trades whose flows can be backed by the storage. This is the asset-backed trading principle. When the storage has volume-dependent injection or withdrawal rates, there may actually be no trades which can be exactly absorbed by the storage and at the same time use the storage capacities fully. In such situations it is common practice to calculate the optimal trades on a daily basis and then to spread the volumes over the products which are actually traded, such as months, quarters and seasons. In general, the intrinsic value, if it can be traded in the market, provides an immediate value and forms the lower bound to what can be actually achieved. The optimization for the intrinsic calculation can be based on linear-programming (possibly with integers) or on dynamic programming.

The rolling intrinsic approach is very similar to the intrinsic, but also considers profits of rebalancing the portfolio over time. At every rehedge date a new intrinsic optimization is executed, but including an initial position. This initial position is taken from the intrinsic optimization and any subsequent rebalancing trades. The rolling intrinsic trading strategy is relatively popular among traders, because it is a safe strategy (the profit cannot go below intrinsic) which can be easily explained to others. In order to judge the potential future value of the rolling intrinsic approach, a representative set of potential future market price developments has to be simulated. For each simulation and each rehedge date the rolling intrinsic approach requires a separate intrinsic optimization, which may make it somewhat slow to calculate. The estimated future roll profits, averaged over the simulations, largely depend on the methodology to describe the forward price dynamics. Roll trades are only profitable if the portfolio can be rebalanced, which is typically when a forward spread changes sign. Such spread sign reversals tend to happen in the shorter end of the forward curve. In any case, a fair rolling intrinsic valuation depends heavily on a realistic price process. Hence, a multi-factor price model, with multiple stochastic factors, is needed. The first (known) description of rolling intrinsic for gas storage is in Gray and Khandelwal (2004). Another article describing this approach is from Bjerksund et al. (2011). It should be noted though that they overestimate the benefits of this approach, mainly because they ignore the requirement that forward contracts should be actually traded.

The basket of spreads approach treats a gas storage as a set of time spread options. As a simple example, suppose four quarters ahead can be traded and the intrinsic strategy is to buy the Jul–Sep forward and sell the same volume in the Jan–Mar forward of the following year. Then at any future date until end