THE ECONOMICS OF STORAGE: LESSONS FROM GERMAN NATURAL GAS FOR GLOBAL HYDROGEN

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Overview

Certain underground storage types, such as salt caverns, have the capability to store hydrogen, highlighting potential parallels with natural gas storage. Underground hydrogen storage (UHS) offers a solution to ensure a reliable energy supply when demand is fluctuating. Insights into the dynamics of natural gas storage (such as operation, utilization and investment) could be valuable for future hydrogen storage developments. The development of sufficient and efficient hydrogen infrastructure will be key to deploy in particular hydrogen based on renewable energy sources.

Three types of geological underground formation are used for storing natural gas today: depleted oil or gas fields, aquifers, and caverns. Cavern storage typically is carried out in salt formations which are also apt to host hydrogen storage, unlike the two other natural gas storage types (e.g., Ozarslan, 2012, Amirthan & Perera, 2022). Salt caverns for natural gas storage are man-made structures. Put differently, there can be investment in more of these caverns if a future hydrogen economy requires more storage capacity.

Much of the existing literature examines natural gas storage in the context of price dynamics, volatility, market arbitrage opportunities, and its role in deregulated markets. While valuable insights into potential drivers of storage investment, such as deregulation, demand, seasonality, and supply security, are often mentioned indirectly, there is no distinct strand of literature explicitly focusing on the determinants of investment in storage capacity. Given the critical role that storage plays in natural gas markets, this analysis aims to fill this gap by explicitly analyzing the factors driving investment in (underground) storage.

The aim of the paper is to develop an empirical model of storage operations and investments that examines the factors of high profit expectations of storage operators. We are specifically interested in the economic factors that have driven the construction of salt caverns for natural gas storage in the past decades in order to deduct whether the same drivers can support the expansion of UHS.

Methods

Literature on underground gas storage economics is relatively scarce, in particular for Europe. Stronzik et al. (2008) and Neumann and Zachmann (2009) provide an early analysis of the gas storage capacity investment "wave" of the 2000s. Yet, more updated research on the European case is missing. Generally, gas storage operators can be considered agents that provide infrastructure for market participants or optimize their gas supply between periods of low demand / prices (when quantities are injected into storage) and periods of high demand / prices (when quantities are withdrawn from storage) (e.g., Chaton et al., 2008). The arbitrage (storage cycle) can be between summer and winter, but can also be on a much shorter time scale to benefit from price variations (e.g., de Jong, 2015).

Data from GIE shows that storage capacity in Germany increased significantly between 1999 and 2018, a period characterized by gradual market liberalization (Figure 1). During this time, capacity rose from approximately 500,000 TJ in 1999 to 770,000 TJ in 2018 (GIE). This growth was largely driven by the development of salt cavern facilities, which technically offer the highest deliverability rates, are ideal for responding to short term market fluctuations and are also prone to host hydrogen in the future.

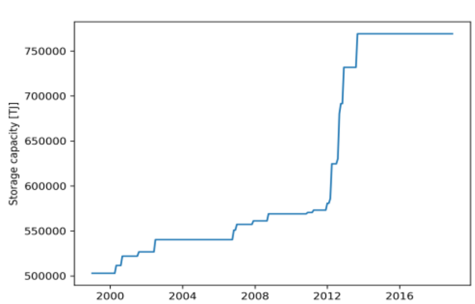

Figure 1: Capacity of underground gas storage in Germany over time (Source: GIE)

Overall, data for an empirical analysis is scarce, often not available in the same frequency and some data may not fulfill required assumptions (i.e., being non-stationary). There is a potential issue of endogeneity bias in our model, as some explanatory variables could be correlated with the error term. An ARDL model with appropriate lag selection can yield consistent estimates of long-run parameters and valid t-statistics even in the presence of endogenous explanatory variables (Pesaran and Shin 2002). Using a lagged variable approach helps mitigate simultaneity bias caused by endogeneity, as demonstrated by Jamissen et al. (2024). As of today, our dataset spans the period from 1999 to 2018 with a monthly frequency. This extended time frame enables us to capture significant market fluctuations and analyze how various factors influence gas storage utilization under differing economic and market conditions. This period experienced a notable expansion of salt cavern facilities, allowing for an assessment of their impact on storage balance. Furthermore, this period includes key regulatory events that shaped gas market dynamics in Europe. The gradual liberalization of the gas market may have increased price volatility, thereby enhancing the strategic use of gas storage for arbitrage opportunities. Policy developments, such as the nuclear phase-out in 2002 and 2011, likely influenced the relative attractiveness of natural gas as an energy source. Including these years provides a deeper understanding of current gas market dynamics and adds relevance for evaluating future market conditions.

Results

The analysis has several preliminary findings. Natural gas prices show a positive and significant relationship with storage utilization, supporting the hypothesis that natural gas is withdrawn when prices are high. The results further confirm that storage utilization is driven by supply and demand dynamics, with significant relationships observed for total natural gas consumption, imports, and heating degree days, underlining the importance of large consumers' storage patterns. Other variables, such as electricity generation (a smaller consumer of gas), import diversity, storage capacity in place, and dummies for market liberalization and the coal and nuclear phase-outs, show insignificant or mixed results.

Conclusions

As the transition to net-zero emissions progresses, hydrogen is emerging as a potential energy source with applications similar to natural gas. Underground hydrogen storage offers a solution to ensure a reliable hydrogen supply when its supply and demand are fluctuating. Our results indicate that the largest consumers are the most important drivers for storage utilization. In a future hydrogen economy, this is likely to be the industrial sector – as opposed to residential heating today. Yet, it remains to be seen whether the role of industrial demand will be big enough to influence pricing and, therefore, the storage incentives.

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