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Experience curve for natural gas production by hydraulic fracturing

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ABSTRACT

From 2007 to 2012 shale gas production in the US expanded at an astounding average growth rate of over 50%/yr, and thereby increased nearly tenfold over this short time period alone. Hydraulic fracturing technology, or "fracking", as well as new directional drilling techniques, played key roles in this shale gas revolution, by allowing for extraction of natural gas from previously unviable shale resources. Although hydraulic fracturing technology had been around for decades, it only recently became commercially attractive for large-scale implementation. As the production of shale gas rapidly increased in the US over the past decade, the wellhead price of natural gas dropped substantially. In this paper we express the relationship between wellhead price and cumulative natural gas output in terms of an experience curve, and obtain a learning rate of 13% for the industry using hydraulic fracturing technology. This learning rate represents a measure for the know-how and skills accumulated thus far by the US shale gas industry. The use of experience curves for renewable energy options such as solar and wind power has allowed analysts, practitioners, and policy makers to assess potential price reductions, and underlying cost decreases, for these technologies in the future. The reasons for price reductions of hydraulic fracturing are fundamentally different from those behind renewable energy technologies – hence they cannot be directly compared – and hydraulic fracturing may soon reach, or maybe has already attained, a lower bound for further price reductions, for instance as a result of its water requirements or environmental footprint. Yet, understanding learning-by-doing phenomena as expressed by an industry-wide experience curve for shale gas production can be useful for strategic planning in the gas sector, as well as assist environmental policy design, and serve more broadly as input for projections of energy system developments.

1. Introduction

Hydraulic fracturing is the process of drilling into a rock formation and injecting at high pressure a mixture of sand, water, and chemicals with the goal of extracting gas or oil from known fossil fuel reserves. This technique, combined with advancements in horizontal drilling technologies, spurred the massive increase of shale gas production in the US over the past 10 years. Beginning around 2005, the shale gas revolution has helped the US reach unprecedented levels of natural gas production. Between 2007 and 2012 shale gas production in the US expanded at an average growth rate of more than 50%/yr (EIA, 2015b).[1] Shale gas production through hydraulic fracturing grew nearly tenfold over this time frame, and the fraction of total natural gas produced through fracturing technology (today around 50%) has increased dramatically.

Unsurprisingly, the increase of unconventional gas production impacted the US natural gas market, causing a sharp decline in the wellhead price (Mazur, 2012). As hydraulic fracturing techniques and drilling technology continue to develop, resulting in additional production increases, further price declines are possible. Both the private and public sectors value analysis regarding the potential effects on market prices of continued growth in unconventional gas production. In this article, based on an inspection of progress achieved in the field of hydraulic fracturing technology so far, we provide an indicator for potential future gas price reductions.

While plenty of literature exists on price and manufacturing cost reductions, as well as on learning-by-doing phenomena, for a large range of energy technologies (see e.g. McDonald and Schrattenholzer, 2000; Nemet, 2006; Greaker and Sagen, 2008; van Benthem et al., 2008; Neij, 2008; Schoots et al., 2010), comprehensive research on price reductions for the use of hydraulic fracturing technology has not yet been undertaken. As production of unconventional natural gas continues to grow, it is insightful to investigate past and prospective

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[1] Although extraction of natural gas in the US rapidly increased from around 2007, commercial hydraulic fracturing began to take hold about two years earlier, initiating exponential growth of production. We therefore use 2005 as marker for the start of the shale gas revolution

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gas price developments. This article presents an experience curve for the US natural gas industry from the start of the shale gas revolution. We examine the impact of increased shale gas production on the wellhead price of natural gas, and show that a learning-by-doing trend exists that reflects past achievements deriving from the accumulation of experience. This trend may be indicative for future price developments, or even for the prospects of the gas industry as a whole. We present an experience curve that may provide insight into one of the factors determining future gas price levels and that, complemented with other price development indicators as well as ancillary knowledge on limitations to its extrapolation, could possibly be used as empirical information for strategic considerations in industry, as background material for public policy planning, or as input for climate change mitigation research. For instance, in principle this experience curve could be implemented in integrated assessment models as used for low-carbon energy technology diffusion studies such as by the Intergovernmental Panel on Climate Change (IPCC, 2014), although such models normally require cost-data rather than price-based information as input. We end our article by reflecting on whether a price floor for natural gas production could soon be reached, and by listing some of the factors that may slow down future price declines or, inversely, contribute to price increases. We hereby connect to recent literature on this subject matter (see notably IEA, 2015, as well as Aleklett, 2015).

2. Experience curve

Experience curve analysis is a method for expressing the relationship between *price* reductions and cumulative production of a good or technology. The experience curve is related to the learning curve, which is a way of illustrating the relationship between *cost* reductions and cumulative production (see Wene, 2000), for details on the distinction between these two concepts). Based on the correlation between price and production observed for the past, experience curves yield information for potential price reductions in the future. The steepness of the experience curve, expressed by the value of the learning rate, identifies the rapidity of structural market, manufacturing, or industry change for in principle any technology. The experience curve methodology stipulates that every doubling of cumulative production of a certain commodity or technology generates a constant relative reduction (in %) of its price, which is the learning rate.

Both engineers and economists have developed and used experience curves to assist the formulation of public policy as well as the design of investment strategies. They have, for instance, done so for renewable energy technologies, the price of which – partly in response to private sector initiatives and public policies stimulating their deployment – has fallen steadily in recent times, as producers and users exercise economies-of-scale and gain experience from learning-by-doing and other mechanisms. Analyzed over extended periods of time, technological learning involves stable long-term price declines, while studies over short-term time scales give evidence of price evolutions with sometimes great variability that occasionally yields much higher or substantially lower learning rates for brief intervals than the long-term average. Manufacturing processes or entire industries for energy technologies, like for technologies in many other sectors, can be characterized by a median learning rate of typically around 20% (McDonald and Schrattenholzer, 2000).

For many technologies, experience curves have been developed from a perspective of industry-wide learning (see, for example, Ferioli et al., 2009). This is the approach we also adopt here. In order to determine an experience curve for hydraulic fracturing in the natural gas industry, we gathered historical shale gas production data and price level data from the US Energy Information Administration (EIA, 2014). In Fig. 1 we reproduce the cumulative shale gas production and wellhead price data that we retrieved for the US between 1997 and

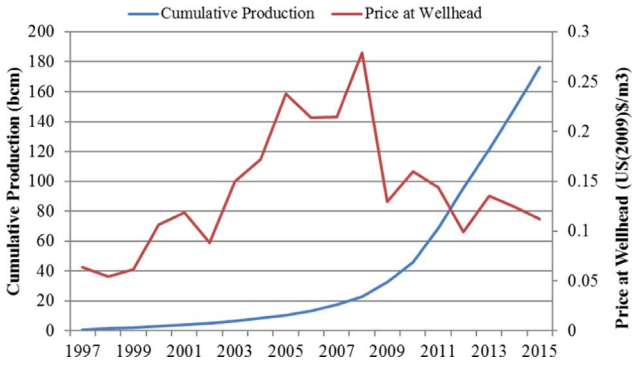

Fig. 1. Cumulative Production of Shale Gas and Price of Natural Gas. (Data from 1997 to 2015).

2015. We converted these data into SI units and expressed prices in constant US(2009)$ terms. Since the publication of US natural gas wellhead prices ceased in 2012, we had to deduce the wellhead price data for 2013–2015: in the Appendix we explain how we did this. Natural gas prices may be subject to a variety of factors that are undesirable from an experience curve analysis point of view, including market fluctuations and manipulations, supply constraints and demand uncertainties, but for our purpose – determining an industry-wide learning rate – these are the most representative data that we could possibly retrieve.

Two clear trends can be detected in Fig. 1: (1) cumulative production of shale gas has increased exponentially over the past decade, and (2) the wellhead price of natural gas has significantly decreased since about 2007, roughly by a factor of two.[2] This observation inspired us to create an experience curve for the industry using hydraulic fracturing technology, by expressing the recently achieved reductions in natural gas prices as function of the cumulative production of shale gas in this industrial sector. The starting point for our experience curve analysis is 2005, since this year represents the beginning of the shale gas revolution. The equation below is used to determine the experience curve, the slope of which is the learning rate, which constitutes a measure for the progress recently attained by the natural gas industry.

$$P(x) = P(x_0)\left(\frac{x}{x_0}\right)^{-L}$$

x: Cumulative output
$P(x)$: Price at cumulative output
L: Learning parameter
$LR = 1-2^{-L}$: Learning rate

Through a regression of our data on the basis of this equation it is easy to visualize the experience curve and calculate the learning rate as the relative reduction of natural gas prices (in %) with every doubling of cumulative production of shale gas. The experience curve we constructed is shown in Fig. 2, which clearly illustrates the learning effect. As is common practice for this methodology, our data are plotted on a double-logarithmic scale, since this allows for the direct calculation of the learning rate based on the steepness of the downward sloping straight line. Due to a lack of publicly available data on specific production costs, the data used in this graph are the wellhead prices

[2] Note that during the early years of the decade prior to 2005 natural gas prices also were particularly low. An explanation for this early price dip falls beyond the scope of this paper.