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Technological progress and the availability of European oil and gas resources

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ABSTRACT

This paper estimates supply cost curves for conventional oil and gas in Europe. Oil and gas volumes are distributed across five categories that are based on production costs. The resulting supply figures are intended to be long term representations of how quantities vary with production costs. Both economic and physical measures are used since each provides practical information with respect to the concerns some energy commentators have expressed about oil and gas scarcity in the near future. Supply cost curves incorporating the effect of annual technological advancement (i.e. productivity gains) on production costs to the year 2030 are also estimated. On the quantity side, the curves include volumes from geological provinces not previously assessed. Results indicate that conventional oil and gas in Europe is abundant and can likely be produced at costs below current and projected market oil and gas prices.

1. Introduction

Oil and gas resources have provided much of the world's energy in the 20th century and are expected to be an important part of the energy mix well into the 21st century [1]. Currently, conventional oil and gas provides approximately 65% of primary energy consumption in Europe [2]. However, energy security in the region remains a concern. The concern is reinforced due to Europe's dependence on oil and gas from other regions. In addition, many commentators fear domestic oil and gas resource depletion will produce significant supply scarcities in the short term, i.e., well before 2020. Thus, the purpose of this analysis is to address the subject by estimating conventional oil and gas supply cost curves for the region.

Continued demand for oil- and gas-based energy services throughout the 21st century is expected to induce technological change that could lower future production cost levels. On the other hand, environmental considerations could adversely affect oil and gas production costs, especially if unconventional resources are considered. Production of these resources typically have larger environmental impacts, including increased greenhouse gases emitted during the extraction and upgrading processes. Emissions penalties could change the shapes of the supply curves, as unconventional oil and gas would become relatively more expensive. The implementation of carbon capture and storage (CCS) at extraction sites could also increase cost, though presumably the cost would be lower than that resulting from the imposition of emissions penalties. Meanwhile, enhanced oil and gas recovery with CO_2 injection would be potentially less expensive due to emissions offsets based on sequestered CO_2.

From an economic point of view, relative prices will determine the dominance of oil and natural gas versus other fuels [3]. To give an example, a significant tax on carbon would increase the relative price of coal versus gas. This would lead to investment and technological advancement across the gas industry and thus induce substitution from coal to gas by decreasing the relative price of gas.

The approach for developing the conventional supply cost curves in this study is based on [4] and begins by using European oil (including natural gas liquids – NGL) and gas volumes estimated by the Variable Shape Distribution (VSD) model [5]. The oil and gas volumes are distributed into several classes based on resource quality. Every class is then assigned lower and upper bounds of production costs, resulting in supply cost curves. For both oil and gas, two curves are developed – one is based on current technology and the other on technology performance assumed for 2030.

2. Paradigm choice

There are two common paradigms for assessing non-renewable resources: the fixed stock versus opportunity cost paradigms. The former observes that the earth is finite; therefore, the supply of any commodity, such as oil or gas, must also be finite. Demand, on the other hand, is variable. Consequently, it is only a matter of time before demand consumes all of the fixed stock. Although the fixed stock paradigm seems logical, economists often argue that the methodology is less useful than the opportunity cost paradigm [6]. The latter uses measures—such as prices, production

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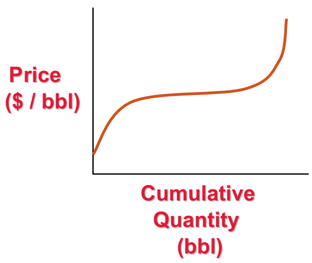

Fig. 1. Cumulative supply curve representing stocks for all time.

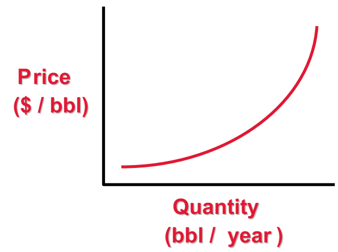

Fig. 2. Traditional supply curve representing a specified time period, such as a month or year.

costs, and the value of reserves in the ground—of what society has to give up to produce another unit in order to assess the effects of depletion and long run trends in availability. If the real price of oil rises over the long run, for instance, this would imply the oil is becoming more scarce.

In spite of the appropriateness of the opportunity cost paradigm, the fixed stock paradigm may be useful when assessing oil and gas resources in particular. The reason is that these may be the only major commodities where commentators are predicting shortages in the near term. Therefore, if reasonable estimates of oil and gas volumes available at some specified price level appear sufficient to cover reasonable estimates of future demand, this provides practical information with respect to the concerns some have expressed.

In this paper we use both economic and physical measures to assess the availability of oil and gas resources in Europe. First, we distribute estimates of the stock of available supply across various production cost categories. We also introduce a time dimension into the supply curve estimation by assessing the role of technological change to the year 2030. In particular, by incorporating the effects of productivity gains on production costs over time we are also utilizing the opportunity cost paradigm.

The resulting supply cost curves can be considered long term availability curves, or approximate cumulative supply curves. There are some important differences between that traditional supply curve and the cumulative supply curve. The latter, which was first proposed by [7], shows how the total or cumulative supply of oil and gas varies over all time with price (see Fig. 1). It differs from the traditional supply curve, which shows the quantity of a resource offered to the market at various prices during a specific time period, such as a month or year (see Fig. 2). In addition, the supply figures provided by the cumulative supply curve are stock variables, unlike the traditional supply curve where they are flow variables that can continue from one period to the next.

3. VSD model

Oil and gas endowment volumes, which are inputs into the supply cost curves, are estimated with a previously defined Variable Shape Distribution (VSD) model [8]. According to the United States Geological Survey (USGS), World Petroleum Assessment [9], endowment refers to the sum of known volumes (cumulative production plus remaining reserves) and undiscovered volumes. The VSD, a statistical method known as size distribution analysis, calculates the endowment volumes in European provinces that have not previously been assessed.[2] This type of analysis has historically been successful in complementing geological techniques used to estimate resources in previously unassessed areas [10]. In this study, the VSD model is only briefly described as the focus is on supply cost curve estimation.

Traditionally, all the methods used to forecast oil and gas volumes have been "based on an assumed form of the size-frequency distribution of the natural population of oil and gas accumulations" [10]. The lognormal and Pareto (fractal) distributions are common size distribution models used to estimate volumes of unassessed areas. Some researchers believe that the distribution of nature's resources follow lognormal distributions [11]. Other researchers claim the lognormal distribution provides overly pessimistic results [12]. More recently, it has generally been acknowledged that the Pareto distribution tends to overestimate oil and gas resources, while the lognormal distribution tends to underestimate them.

The VSD is unique in that we first observe the curvature (on a log–log plot) given by the size and number of assessed provinces by [9]. We then develop the VSD model which allows the data to determine the specified relationship between the size and number of provinces. In [8], the model has been used successfully, typically with coefficients of determination (R^2) equal to or greater than 0.98, to match available global data for conventional oil, gas, and natural gas liquids. The close matches allow us to extend the model out of sample to include previously unassessed provinces in the analysis. As is common in size distribution models, the original sample contains the largest provinces, meaning that most of those previously unassessed will be smaller in terms of volumes [13]. For a detailed mathematical description of the VSD, refer to [8].

Recently, the VSD model was validated in [5] by comparing VSD-calculated and actual European endowment volumes published by [9]. Examples of the results, for conventional oil (including NGL) and gas, are presented in Fig. 3. The plots show the number (rank) versus size of oil and gas endowment provinces estimated by [5,9]. For the case of oil, the actual endowment represented by the lower curve in Fig. 3 corresponds to 12 geological provinces assessed by [9]. This endowment, estimated at approximately 102 billion barrel of oil equivalent (BBOE), compares well with the 101 BBOE calculated by the VSD model. The coefficient of determination (R^2) is equal to 0.99. Note that these volumes do not include heavy oil, oil sands, oil shale, and offshore provinces with water depths greater than 2000 m in some cases and 4000 m in others.[3] The VSD model was then used to estimate the conventional oil volumes of the 62 provinces recognized by the USGS to exist in Europe, out of which 50 had not been evaluated previously. The black solid curve, generated by the VSD model, corresponds to 62 provinces and gives an oil endowment of 146 BBOE. If the effect of reserve growth of 43% is taken into account, this volume increases to 208 BBOE and is represented by the dashed curve. For more on re-

[2] As defined by [9, p. GL-4], a petroleum province is an "area having characteristic dimensions of perhaps hundreds to thousands of squared kilometers encompassing a natural geologic entity (e.g. sedimentary basin, thrust belt, delta) or some combination of contiguous geologic entities." The study adopted a 30-year time horizon and so ignored those provinces that were not expected to be producing oil and gas within that period. According to [9, p. AR-3], the areas assessed were "those judged to be significant on a world scale in terms of known petroleum volumes, geologic potential for new petroleum discoveries, and political or societal importance."

[3] Originally, [9] delineated offshore province areas to water depths of 2000 m but then extended the analysis to several 4000 m areas due to rapidly developing drilling and production technology.