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Testing Hubbert

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Abstract

The Hubbert theory of oil depletion, which states that oil production in large regions follows a bell-shaped curve over time, has been cited as a method to predict the future of global oil production. However, the assumptions of the Hubbert method have never been rigorously tested with a large, publicly available data set. In this paper, three assumptions of the modern Hubbert theory are tested using data from 139 oil producing regions. These regions are sub-national (United States state-level, United States regional-level), national, and multi-national (subcontinental and continental) in scale. We test the assumption that oil production follows a bell-shaped curve by generating best-fitting curves for each region using six models and comparing the quality of fit across models. We also test the assumptions that production over time in a region tends to be symmetric, and that production is more bell-shaped in larger regions than in smaller regions.

Keywords: Petroleum; Hubbert theory; Oil depletion

1. Introduction and context

Since the beginning of commercial exploitation of oil, there has been great interest in two related questions: how much oil exists in the world, and when will we run out of oil? This very old discussion has recently resurfaced, as interest in oil depletion has increased along with increasing oil prices. Recent projections of global oil production have been made using a set of methods commonly referred to as the "Hubbert theory" of oil depletion, but these projections have been rejected by those who doubt the effectiveness of the method. Importantly, however, the assumptions of the Hubbert method have never been tested against possible alternatives in a peer-reviewed format using a large, publicly available data set. This paper tests some aspects of the Hubbert theory against other plausible theories of how oil production varies over time.

1.1. The Hubbert theory of oil depletion

The Hubbert theory of oil depletion was developed by Hubbert (1956). Hubbert (1956) projected future United States oil production based on two estimates of the total amount of oil that would be produced in the United States. He did not provide a functional form for his prediction in this early paper, but instead fit past production to a bell-shaped curve in which the area under the curve was equal to his estimates of the amount of total oil available. Using this method, he arrived at two predicted dates for peak production, one in the mid-1960s, the other around 1970.

Hubbert later added other elements to his analysis (Hubbert, 1959). First, he specified a functional form for his prediction, the logistic curve, stating that cumulative production over time would follow a logistic curve, and thus that yearly production would follow the first derivative of the logistic curve, which is bell-shaped. He also analyzed patterns of discovery and production. He plotted cumulated discoveries alongside cumulated production and noted that the curves were similar in shape but shifted in time (Hubbert, 1959). With this paper, most of the major elements of modern Hubbert analysis were developed.

United States oil production peaked in 1970, and with this vindication the Hubbert theory became an important tool for those concerned about depletion of natural resources (Deffeyes, 2001). This success caused Hubbert and others to project global oil production. The recent

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explosion of interest in the Hubbert theory started in the 1990s with Campbell's efforts to use it to predict global oil production (Campbell and Laherrere, 1998).

Modern Hubbert modeling is really a constellation of techniques, many of which were developed by Hubbert himself in his early papers, and some of which were not. The methods used vary widely by analyst, but the core techniques of modern Hubbert analysis are as follows:

Analysis of past discoveries: discovery data are plotted, and sometimes adjusted for reserve growth, and a best-fitting curve (typically logistic or Gaussian) is matched to discoveries.

Estimation of future oil discoveries: total amounts of oil to be found are extrapolated in a number of ways, including the "creaming curve" method, which estimates an asymptote for total discoveries when plotting cumulative discoveries by cumulative new field wildcat wells drilled (Campbell and Laherrere, 1998); by using a newer technique sometimes called "Hubbert linearization" to project ultimate recovery (Deffeyes, 2001); or by using a statistical relationship such as the parabolic fractal law to infer the size of undiscovered fields using the distribution of already-discovered field sizes (Laherrere, 1996).

Projection of future production: using discovery data in conjunction with estimated future discoveries, a curve (again, typically logistic or Gaussian) is fit to historical production data such that the area under the curve equals the sum of discovered and not yet discovered oil.

It should be emphasized that a key portion of the Hubbert methodology is the estimation of ultimate production. Indeed, estimation of ultimate production has a larger effect on the accuracy of projections than other aspects of the methodology because ultimate production, or the area under the production curve, strongly affects the path of production over time. However, we do not test the accuracy of previous estimates of ultimate production here, but seek instead to test other assumptions of the Hubbert model as commonly practiced.

A number of assumptions are commonly made in modern Hubbert modeling, although some of these were not developed by Hubbert himself, and different analysts relax some of these assumptions. Commonly used assumptions include the following: that production follows a bell-shaped curve over time; that production is symmetric over time (i.e. the decline in production will mirror the increase in production, and the year of maximum production, or peak year, occurs when the resource is half depleted); that production will follow discovery in functional form and with a constant time lag; and, lastly, that production increases and decreases in a single "up–down" cycle without multiple peaks.

1.2. Alternative models of oil depletion

A number of models of oil depletion have been used to forecast future oil production. The most simple of these models, and often not thought of as a "model" at all, is the reserve to production ratio (R/P), or simply the quantity of current reserves divided by current production. Criticisms of this methodology are too numerous to cite, but the general problem with this analysis is that neither reserves nor production are constant over time, making R/P nearly valueless as a forecasting technique.

Modified versions of the Hubbert methodology have been developed. These include a model by Hallock et al. (2004) which uses a modified version of the bell-shaped curve. This curve peaks at 60% of ultimate production instead of the typical 50%. This method implies an asymmetric shape to production and a steeper rate of decline than increase.

Another simple model is a linear oil depletion model, where production increases and decreases linearly. This model has never received much attention, but Hirsch (2005) notes that United States production in the period 1945–2000 fits a linear production profile better than a bell-shaped curve.

Exponential models are another possible simple model. Hubbert used an exponential fit in the 1956 paper where he first presents his method, plotting United States coal and oil production on a semi-logarithmic scale, noting the straight line over much of history, indicating exponential growth (Hubbert, 1956). Also, Wood et al. (2000) assumed a 2% exponential growth for world oil production, followed by a decline "at an R/P ratio of 10". This decline at a constant R/P of 10 is equivalent to exponential decline of 10% per year.

Laherrere (2005) has constructed multi-cycle models where production follows a number of discovery cycles with a constant shift in time. These curves have been prepared for regions such as France and Illinois, where there is a significant bimodal discovery trend that can be mapped onto the bimodal production trend.

Hirsch studied peaking rates of a small number of production regions, including the United States, Texas, the United Kingdom, and Norway, and noted that production peaks have tended to be steeper and sharper than predicted by the Hubbert theory (Hirsch, 2005). Some bottom-up modeling efforts, using models that simulate finding and extracting resources over time, suggest that production would be roughly bell-shaped, but not necessarily symmetric (Bardi, 2005; Reynolds, 1999). Bardi (2005) critiques the assumption of symmetrical production over time, stating that there is "no magic in the 'midpoint' of the production of a mineral resource" and that production can exhibit a decline rate greater than the rate of increase.

1.3. Problems with current depletion analysis

There are significant difficulties with current methods of predicting future oil production. Two classes of problems emerge: those resulting from poor data, and those resulting from uncertain terminology and methodologies.