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Bottom-up modeling of oil production: A review of approaches

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HIGHLIGHTS

- Bottom-up models are influential in the study of the oil production supply chain.
- Nine existing bottom-up models are reviewed.
- The high level of detail is of questionable value for predictive accuracy.
- There is a potential for more systematic sensitivity analysis.

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ABSTRACT

Bottom-up models of oil production are continuously being used to guide investments and policymaking. Compared to simpler top-down models, bottom-up models have a number of advantages due to their modularity, flexibility and concreteness. The purposes of this paper is to identify the crucial modeling challenges, compare the different ways in which nine existing models handle them, assess the appropriateness of these models, and point to possibilities of further development. The conclusions are that the high level of detail in bottom-up models is of questionable value for predictive accuracy, but of great value for identifying areas of uncertainty and new research questions. There is a potential for improved qualitative insights through systematic sensitivity analysis. This potential is at present largely unrealized.

1. Introduction

1.1. Oil production models

Forecasts and scenarios of future oil production present an embarrassment of riches. Although the spectacular divergence in outlooks might appear puzzling, it should not be treated as mysterious or inevitable. Provided that the outlooks are not merely products of free-floating speculation, any differences in results can be traced down to differences in the underlying models and their assumptions. There are numerous modeling approaches, but they can be grouped into two broad classes:

- *Top-down:* models that forecast aggregate production through some form of extrapolation of aggregate variables (examples are simple curve-fitting, system dynamic simulations and macroeconometric models)
- *Bottom-up:* models that represent the supply chain of the upstream oil industry, and forecast aggregate production as the sum of production from smaller units.

In a previous work (Jakobsson et al., 2012) we focused on modeling from a theoretical and qualitative standpoint. We argued that bottom-up models are useful as conceptual tools, in that they serve to sharpen intuition and promote a common understanding of oil depletion among scientists from different disciplines. The reason is that bottom-up models have a number of advantages compared to top-down models:

- Modularity, which helps to identify and isolate areas of scientific uncertainty or disagreement
- Flexibility in accommodating both physical and economic principles
- Concreteness, due to the direct correspondence between modeling concepts and observable objects.

If the potential as a theoretical tool is not enough to spur an increased interest in these models within the forecasting community, their practical influence provides another strong motivation. As for top-down models, it is fair to say that their impact on decision-making is insignificant compared to the controversy they generate. This is particularly true of the Hubbert curve (Hubbert, 1956, 1982). In contrast, bottom-up models are continuously being used by energy companies, energy consultancy firms, banks and public institutions to guide investments and policymaking.

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The most well-known applications of bottom-up models would likely be the scenarios presented in the *World Energy Outlook* of the International Energy Agency (IEA) and the *Annual Energy Outlook* of the U.S. Energy Information Administration (EIA).

In this paper, we turn to the use of bottom-up models in making actual quantitative scenarios. Although bottom-up models have not yet received the attention that their influence would justify, two pioneering studies have served as important starting points for this paper. In his comprehensive review of oil forecasting methodologies, Brandt (2009, 2010) provides a brief assessment of the bottom-up approach. Brandt concludes that this approach holds promise in short-term projections and enables detailed sensitivity analyses, but at the same time requires a lot of assumptions and thus does not eliminate genuine uncertainty about the future. Bentley et al. (2009) and Sorrell et al. (2010) compare scenarios generated by 14 contemporary models, several of which are bottom-up. The authors carefully document modeling parameters with focus on two important aspects: the assumed amount of known and yet unknown recoverable oil resources; and the explicitly or implicitly assumed rate of production decline in fields and regions. We build upon this methodological review by widening the scope to the entire oil supply chain (Fig. 1). Our purpose with this paper is to:

- Describe the oil supply chain, with focus on the economic and geologic issues that are the most relevant in modeling
- Identify the crucial modeling challenges, and compare the different ways in which past modelers have handled them
- Assess the appropriateness of existing models, and point to possibilities of further development.

2. General model characteristics

2.1. Models reviewed

We have selected models that fulfill the following criteria:

- Represent the upstream oil supply chain to some degree, that is, the exploration for, development of, and production of oil resources.
- Apply to conventional oil production. Conventional oil is here defined as occurring in discrete accumulations bounded by a down-dip water contact and being significantly affected by the buoyancy of petroleum in water (United States Geological Survey (USGS), 2000).
- Designed with the purpose to generate quantitative scenarios, not merely theoretical insights.

Our model inventory is not intended to be exhaustive. Furthermore, due to the rather strict selection criteria, some models with a bottom-up orientation are excluded although they are relevant in the broader oil modeling context. One example is the ACEGES model, presented by Voudouris et al. (2011), which yields probabilistic production scenarios aggregated from country level. We have identified nine sufficiently well-documented bottom-up models from the 1970s and onwards (Table 1). The results are summarized in Tables 2–5.

2.2. The stated purpose of modeling

All the reviewed models have production rate as an output. In some cases, modeling the production rate is the only stated purpose, but several models are also designed to enable investigation of other issues, such as policy evaluation, market power, and energy transitions.

2.3. Geographical and temporal scope

Several models forecast production at the global level, but some are limited to a specific region where detailed industry data is available, such as continental United States or the North Sea. A “typical” forecasting time horizon is about 25 years, although this varies considerably. The most extreme case is EIA-IPPM, which has been used for scenarios with a 200 year horizon.

3. Production profiles

3.1. Smallest production unit

The “smallest production unit” is the term we adopt here for the unit associated with a specified production profile. The most common choice is to have fields as the smallest unit. A field consists of one or several reservoirs associated with the same geological feature. EIA-OLOGSS is the only model with individual wellbores as smallest

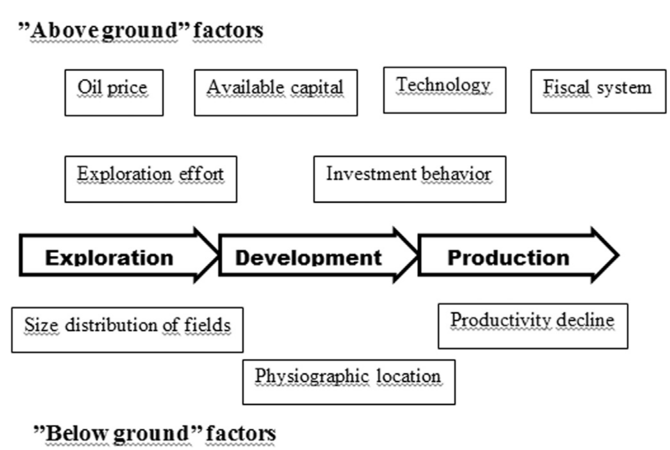

Fig. 1. Schematic illustration of the oil supply chain and some of the factors that enter bottom-up models.

Table 1
The bottom-up models reviewed.

Institution	Abbreviation used in text	Reference
Erasmus University of Rotterdam	O&R	Odell and Rosing (1974)
Massachusetts Institute of Technology	MIT-POOL	Adelman et al. (1976)
Massachusetts Institute of Technology	MIT-AGG	Adelman and Paddock (1980)
Oak Ridge National Laboratory	WESM	Greene et al. (2003)
Statistics Norway	FRISBEE	Aune et al. (2005)
University of Aberdeen	K&S	Kemp and Stephen (2008)
Energy Information Administration	EIA-IPPM	Energy Information Administration (EIA) (2008)
Energy Information Administration	EIA-OLOGSS	Energy Information Administration (EIA) (2005, 2010)
International Energy Agency	IEA-WEM	International Energy Agency (IEA) (2010a)