MODELING PEAK OIL AND THE GEOLOGICAL CONSTRAINTS ON OIL PRODUCTION

Samuel J. Okullo, IVM, samuel.okullo@ivm.vu.nl
Frédéric Reynès, TNO, +31 88 866 26 31, frederic.reynes@tno.nl
Marjan Hofkes, IVM, marjan.hofkes@ivm.vu.nl

Overview

Geological constraints are considered in the context of a Hotelling type extraction-exploration model for an exhaustible resource. It is shown that such constraints, in combination with initially small reserves and strictly convex exploration costs, coherently explains bell-shaped peaks in natural resource extraction, and hence U-shapes in prices. As production increases, marginal profits (marginal revenues less marginal extraction cost) are observed to decline, and as production decreases, they rise at a positive rate that is not necessarily the rate of discount.
A numerical application of the model to the world oil market shows that geological constraints have the potential to substantially increase the future oil price. While some non-OPEC producers are found to increase production in response to higher oil prices induced by the geological constraints, most producers' production declines, leading to a lower peak level for global oil production.

Method

As a starting point, the paper reviews models in the literature that try to account for two important stylized facts regarding oil: (i) production profiles usually exhibit bell-shaped peaks, and (ii) nonrenewable resource prices are often non increasing over a substantial part of a resource's productive life. We point out that although these models do explain how production might peak and why prices may follow U-shaped paths, none of the reviewed models looks at the likely impact of geological constraints.

Then our paper adds to the literature by proposing an additional framework through which peak oil can be studied. To do so, geological constraints are considered in the context of a Hotelling type extraction-exploration model for an exhaustible resource. By first assuming that geological constraints impose an upper bound on the amount producers can extract, and that producers find it optimal not to exceed this bound, we sought to characterize the optimal paths for production. After having derived the model’s optimality conditions, we fully characterize the model's equilibrium. We also discuss alternative specifications and their impacts on the equilibrium. More specifically, impacts of (i) reserve destruction due to extracting above the geologically recommended depletion rate, (ii) spatial extraction and endogenous field opening, and (iii) reserve degradation are discussed.

In order to quantify the impact of geological constraints on prices and production, we then presents comparative results from a numerical simulation using a global oil market model that accounts for the geological constraint and another model that does not.

Results

The nature of our results is both theoretical and empirical.

1. Theoretical results
The paper analytically investigates how geological constraints might alter the producer's optimal extraction decision under different assumptions about reserve size and cost. By proposing a model for the exploitation of a nonrenewable resource that introduces a standard engineering representation of reservoir pressure constraints, as the geological constraint, into a Hotelling type model; we show without relying on demand shifts, technical progress, cost reducing exploration, or endogenous spatial extraction and additions, that for a finite resource base, a bell-

shaped peak in production and hence a U-shape in price occurs provided initial reserves are small, and exploration and reserve development costs are strictly convex. If, however, initial reserves are large, production is found to decline monotonically and price rises monotonically, as in the basic Hotelling model. The introduction of these constraints also generates some interesting implications for marginal profit (marginal revenues less marginal extraction cost), which in the literature is often seen as a relevant measure of scarcity. Our main model indicates that rather than marginal profit rising monotonically at the rate of discount --- as is the case with typical Hotelling models --- it declines (rises) as production rises (falls).

Moreover, we investigate the consequences of three extensions to the main model. Allowing for accelerated extraction which implies that producers can extract above their geologically optimal rate, but in turn face reserve destruction, is found to be optimal in certain circumstances: this occurs when the marginal value of current extraction is at least as great as the marginal value of lost reserves. Although accelerated depletion does influence the level of production, it still induces the same production profiles as in the main model. Extending the main model for endogenous field opening reinforces the result that the life cycle of resource exploitation can be described as one with a bell-shaped peak, and that marginal profits and price could decline over a large part of the horizon. Allowing costs to rise with depletion of reserves still leads to the same basic paths as in the main model, discoveries however decline faster, leading production to decline faster overtime, and in the case of a bell-shaped peak, to peak earlier.

2. Empirical results

In the final part of the paper, we compare projections for crude oil prices and production when the model includes the geological constraint (depletion constrained path) and when the constraint is not active (Hotelling path). Prices from the depletion constrained model are found to be substantially higher than those from the Hotelling model. Moreover, by comparing scenarios for production, it is observed that while the Hotelling model predicts that Saudi Arabia's production could start declining in 2035, the depletion constrained model indicates declining production starting from 2015. For smaller producers such as Brazil, however, the higher prices induced by the depletion constraint allows them to build up their reserves faster, and in turn extract more than in the Hotelling production path. Their increase in production is, however, insufficient to offset declines from major oil producers.

References

See the full length IAEE Working Paper:

Okullo, S. J., Reynès, F., Hofkes M., Modeling Peak Oil and the Geological Constraints on Oil Production, USAE/IAEE Working Paper Series, March 18, 2012, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2025631.