Energy Policy 44 (2012) 68–78

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

On the portents of peak oil (and other indicators of resource scarcity)

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ARTICLE INFO

Article history:
Received 10 August 2011
Accepted 8 January 2012
Available online 15 February 2012

Keywords:
Resource scarcity
Peak oil
Hotelling

ABSTRACT

Economists have studied various indicators of resource scarcity but largely ignored the phenomenon of "peaking" due to its connection to non-economic (physical) theories of resource exhaustion. I consider peaking from the *economic* point of view, where economic forces determine the shape of the equilibrium extraction path. Within that framework, I ask whether the timing of peak production reveals anything useful about scarcity. I find peaking to be an ambiguous indicator. If someone announced the peak would arrive earlier than expected, and you believed them, you would not know whether the news was good or bad. However, I also show that the traditional economic indicators of resource scarcity (price, cost, and rent) fare no better, and argue that previous studies have misconstrued the connection between changes in underlying scarcity and movements in these traditional indicators.

"Portent: An indication of something important or calamitous about to occur."
thefreedictionary.com

1. Introduction

For better or worse, "peak oil" has gained considerable prominence as an indicator of growing resource scarcity. Since Hubbert (1956) introduced the hypothesis that oil production must reach a maximum and then fall into inexorable decline, economists have remained skeptical. That skepticism is largely due to the fact that Hubbert's methods and predictions treat production of oil as an exogenous process divorced from market incentives. Nevertheless, the general public and numerous scientists from disparate fields remain clearly focused on the prospect of an impending and inevitable decline in oil production and embrace the notion that "peaking" manifests a scarcity that necessarily limits future economic growth. The peak, in other words, is undesirable because it ushers in a new age of painful, and potentially catastrophic, change.[1] Motivated by these sentiments, Campbell and Laherrère (1998) have declared that dating oil's peak is more important even than dating its exhaustion. Consistent with this view, we have seen a virtual tournament among analysts who have attempted to date the peak.[2]

This paper considers the economic implications of peak oil. However, we take a different view of the peaking phenomenon than what is represented by the Hubbert Curve. Any well functioning market economy, endowed with a limited amount of an exhaustible resource, will arrange production through time according to prevailing economic incentives that reflect market fundamentals such as the size of the resource stock, the cost of production, discount rates, the strength of current versus future demand, and the availability of substitutes. In contrast to the Hubbert Curve, where the peaking phenomenon is a physical imperative caused by "running out" of the resource, the forces that regulate production in a market economy might cause production to fall due to insufficient demand, rather than insufficient supply.[3]

Just as the interaction of supply and demand determines the equilibrium price path in a market economy, so too do these forces determine the equilibrium production path. Taking market forces into account does not avoid the inevitable peak, of course, but since both sides of the market (demand as well as supply) are integral to the rate of production, the peaking phenomenon generated within a market economy presumably conveys more information than what is implied by the Hubbert Curve. With this in mind, it seems at least possible that "peak oil" might serve as some kind of useful economic indicator of scarcity. Therefore, despite economists' justifiable rejection of the Hubbert Curve, they may nevertheless reasonably ask whether the phenomenon of peaking within a market economy reveals something important about the state of resource scarcity—something that would not be revealed by market prices or resource rents, for example.

A major objective of this paper is therefore to explore whether peaking provides a useful economic indicator of scarcity. The

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[1] See, for example, Leigh (2008), Bardi (2005), and Campbell and Laherrére (1998).

[2] Recent attempts to date the peak include Wood et al. (2003), Bartlett (2000), Duncan and Youngquist (1999), and Korpela (2006).

[3] The simple analytics of Hubbert's approach to peak oil are sketched in the appendix.

0301-4215/$ - see front matter
doi:10.1016/j.enpol.2012.01.014

principle I apply to make that determination is very basic and follows Brown and Field (1978), who set forth two criteria by which any indicator of resource scarcity might be judged. The first states quite simply that:

> A minimum condition (for a good index of scarcity) is that the index go up when underlying determinants shift to increase actual or expected demand for the resource relative to actual or expected supply.

The second criterion goes quite a bit further:

> It would be much more useful, furthermore, if it were possible to distinguish the contribution to the changes in the index made by each important determinant of demand and supply shifts.

The second criterion is notable because it requires the indicator to signal not just that a change has occurred, but also the source of the change. Although this may be a desirable characteristic of an ideal indicator, in practice it seems beyond reach, as I argue later. Thus, I will focus on Brown and Field's first criterion, which refers to an exercise in comparative statics and expresses the idea that an indicator of scarcity should provide reliable directional signals of unexpected changes to the balance of supply and demand.

The rest of the paper proceeds as follows. In Section 2, I present within Hotelling's framework the simplest possible model of equilibrium resource depletion and resulting peak production. More realistic (i.e., complicated) models could be explored but they are not of the essence. If peaking signals scarcity, it should be possible to demonstrate that in a simple model. Thus, in Section 3, I examine the comparative static properties of peaking within the simple Hotelling model. The traditional economic indicators of scarcity are subjected to similar analysis in Section 4. That analysis not only demonstrates the limitations of the traditional indicators, but also corrects a common misunderstanding regarding what the previous literature has demonstrated. The findings of the study are summarized in Section 5.

2. Hotelling's peak

Hotelling (1931) pioneered the *economic* study of peak oil, although his work is usually not described in those terms.[4] Because the Hotelling model is well known to many economists, only a cursory review of the simplest possible application is provided here.[5] More elaborate and realistic versions of the Hotelling model have been developed, and, as Gordon (2009) emphasizes, those extensions undoubtedly provide better empirical predictions of real-world production and price trends. However, our goal is not to predict the future, but to determine conceptually whether the peaking phenomenon provides a consistent indicator of scarcity. As we will show, peak oil fails this simple test even in models where the economy is deliberately oversimplified and the depletion phenomenon is entirely straightforward. Adding further complexity (realism) to the model would only increase the degree of ambiguity that surrounds the peaking phenomenon.

Let there be a fixed volume of the depletable resource (R) available at time t_0. The unit cost of production (C) is constant through time, which implies no variations in resource grade and no technological change. The relevant discount rate (r) also remains constant through time. Demand for the resource is given by a constant elasticity demand function and the quantity demanded at any given price is assumed to grow exogenously at the rate g—which may represent the combined force of population growth, economic development, etc.[6] Thus, the demand function can be written as

$$Q_t^d(P_t) = K \times P_t^{\varepsilon} \times e^{gt},$$

where K is a scalar that represents the initial size of market.

Moreover, a perfect substitute for the depletable resource (i.e., a backstop technology) is available in unlimited quantities at constant unit cost (B). The cost of the backstop is assumed to be known but may be relatively high.

Under these conditions, and assuming that markets are competitive and that a full set of futures markets exists, a unique inter-temporal equilibrium exists and is characterized by the price path that satisfies the following three conditions:

(1) $P_t - C = (P_0 - C)e^{rt} \quad \forall t \in (t_0, T)$ [no inter-temporal arbitrage]
(2) $P_T = B$ [transition to backstop at time T]
(3) $\int_{t_0}^{T} Q_t^d(P_t)dt = R$ [resource exhaustion at time T]

Because production of the resource is positive only during the finite interval $[t_0,T]$, it follows that a peak rate of production must exist. Although a closed-form solution does not exist for the date of the peak, it can easily be computed once specific functional forms and parameter values are specified. The timing of the peak will generally depend upon the fundamental economic factors that describe the economy. The peak may come at mid-course (as predicted by Hubbert), or early, or late in the course of exploitation—all depending upon the elasticity of demand, the economic growth rate, the discount rate, the initial volume of resource available, and the cost of producing the depletable resource relative to that of the backstop technology.[7] At issue is whether changes in these underlying economic parameters are consistently reflected in, and might therefore be inferred from, corresponding changes in the timing of the peak.

3. Peaking as an indicator of scarcity

I illustrate the relationship of the Hotelling peak to underlying economic fundamentals using a series of concrete examples. In each case, the long-term elasticity of demand is assumed to be -0.35. The discount rate is 10%, and the initial volume of the resource is arbitrarily assumed to be 4000 units. The unit cost of production is \$20 for the resource versus \$100 for the backstop technology. In what I will refer to as the *Benchmark* scenario, the growth rate of demand is taken as 1.5% per annum, and the

[4] Holland (2008) is one of the very few authors who have explored the timing of peak oil within the Hotelling framework. Greene et al. (2006) also investigate peaking behavior in the context of an economic transition from conventional to unconventional resources. Although Farzin (1995) does not specifically focus on the production peak, he does explore the relationship between a declining (or increasing) production trend and other measures of resource scarcity. Without embracing Hotelling's full equilibrium framework, various authors have shown via ad hoc specifications that economic variables improve the fit of the Hubbert Curve to historical data; see for example Bopp (1980), Kaufmann (1991), Cleveland and Kaufmann (1991), and Kaufmann and Cleveland (2001).

[5] Readers who are interested in the many extensions to the basic model are referred to Hotelling (1931), Herfindahl (1967), Solow (1974), Levhari and Liviatan (1977), Devarajan and Fisher (1981), Krautkraemer (1998), Farzin (1992), etc.

[6] I have also investigated models with linear demand, which give similar results.

[7] Gordon (1967) and Levhari and Liviatan (1977) were among the first to characterize the influence of various economic factors on the shape of the equilibrium path. Indeed, in more elaborate models that incorporate exploration, technological change, etc., the rate of production may peak more than once along the equilibrium path.