The Extraction of Exhaustible Resources

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On December 28th, the Energy Bulletin included a link to a paper called Technology and Petroleum Exhaustion: Evidence from Two Mega-Oilfields (pdf) by two economists, John Malcolm Gowdy and Roxana Julia, from the Rensselaer Polytechnic Institute in New York. Here's the abstract.

> In this paper we use results from the Hotelling model of non-renewable resources to examine the hypothesis that technology may increase petroleum reserves. We present empirical evidence from two well-documented mega-oilfields: the Forties in the North Sea and the Yates in West Texas. Patterns of depletion in these two fields suggest that when a resource is finite, technological improvements do increase supply temporarily. But in these two fields, the effect of new technology was to increase the rate of depletion without altering the fields' ultimate recovery - in line with Hotelling's predictions. Our results imply that temporary low prices may be misleading indicators of future resource scarcity and call into question the future ability of current mega-oilfields to meet a sharp increase in oil demand.

The paper is fairly standard fare for the peak oil community but what turns out to be of interest is the application of the work of Harold Hotelling regarding the Extraction of Exhaustible Resources and their discussion of the economic view of resource scarcity as regards oil. Examining the use of EOR technology in the historic production of Yates (West Texas) and the Forties (UK North Sea), Gowdy and Julia conclude that temporary incremental production gains are offset by later steeper decline rates in the tail end of production without increasing the overall URR. Their main conclusions are essentially that 1) oil is not being treated as a finite resource as the oil field analyses predict and 2) temporary production gains mask real scarcity and result in misleading low oil prices. Let's look at the work of Hotelling in the context of peak oil and see where that goes. This post runs a bit long so I hope you'll bear with me here.

The Hotelling Result

First, here is the Hotelling equation as regards a finite resource from Gowdy and Julia. [Editor's note--open this graphic in a new window, keep it available and continue to read along below. I will refer to this equation again near the end of this post.]

It is only a small exaggeration to say that most contemporary resource economics is a footnote to Hotelling's paper "The Economics of Exhaustible Resources." [13].

Following Krautkraemer [14], the basic Hotelling equation can be written as:

$$\text{Maximize} \int e^{-\delta t}[B(q(t),S(t)) - C(q(t), S(t))]dt \quad (1)$$

subject to:

$$\dot{S}(t) = -q(t), S(t) \geq 0, q(t) \geq 0, S(0) = S_0 \quad (2)$$

where B[q(t), S(t)] represents gross benefits, C[q(t),S(t)] are the extraction costs; S is the remaining stock, δ is the rate of discount, and q(t) is the time path for resource extraction that maximizes the present value of the stream of net benefits from extraction. Notice that this key equation for resource policy only contains discounted monetary units. All information about the physical resource base comes through the price system.

The main insight regards the rate of discount **δ**, which is essentially the same as the interest rate. The main idea, of course, is to maximize returns (profits) at all times. From the Extraction link cited above, we see that

> ...the society maximizes its profit over all times, not just the present time. For this, the value of future profits must be discounted at a rate that is more or less equivalent to the interest rate.
>
> ... this is the fundamental problem in all of exhaustible resource economics, and it was first posed and solved by Harold Hotelling in 1931....
>
> This formulation is known as the Hotelling Rule, and predicts that prices increase at an exponential rate that is equal to the exhange rate. That means, in an economic sense, a mineral deposit in the ground has the same significance as a bond, and is in some sense interchangeable with such a financial instrument.
>
> An overview of the hotelling price path is given in the figure below. As the resource is depleted, the price rises and as the price rises the demand, and hence the consumed quantity, falls. All the while the quantity remaining in the reservoir sinks.

Here is the Hotelling price path from that same paper.

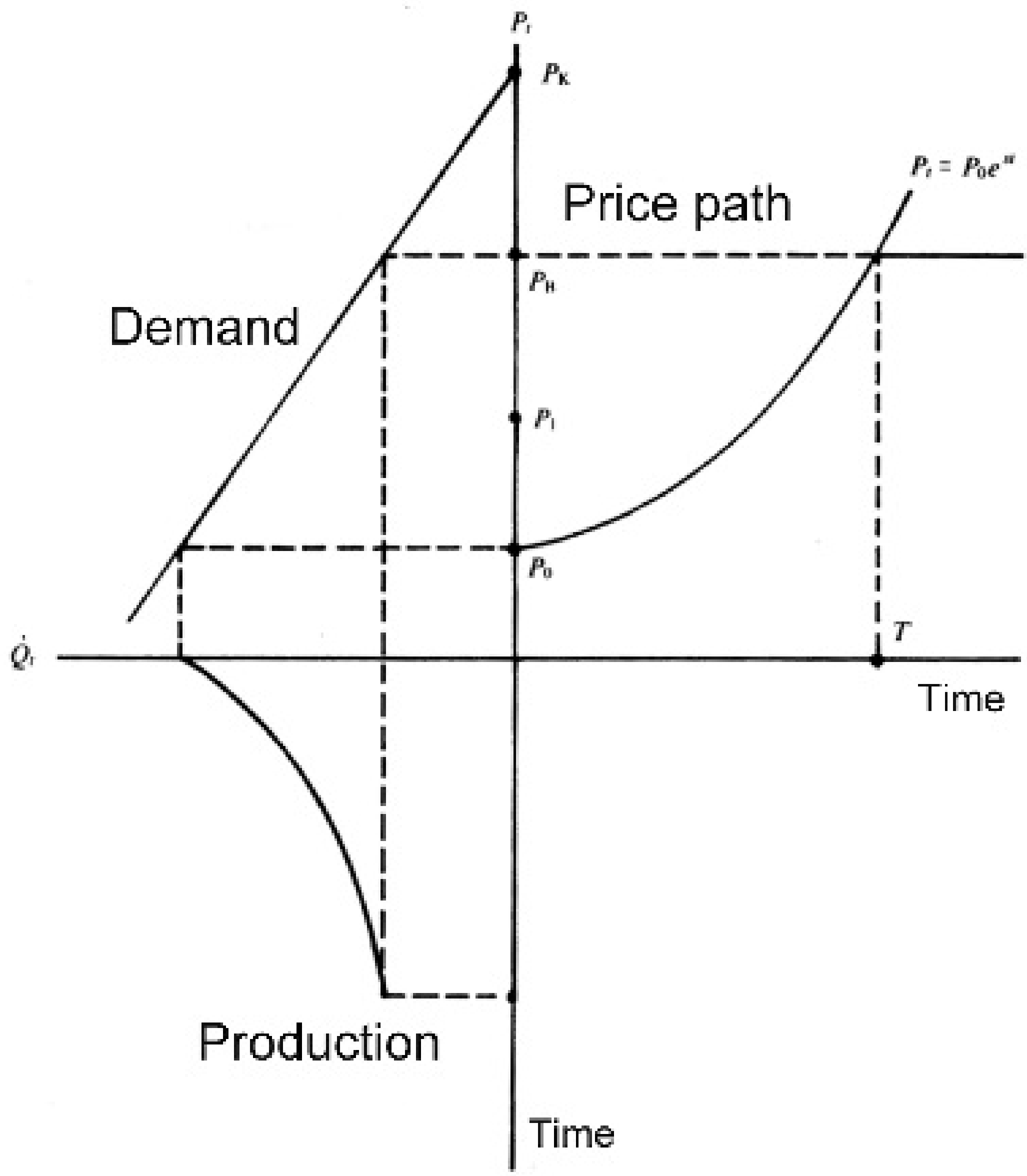

Figure 18.1 The Hotelling price path.

As production of the finite resource decreases (lower left quadrant), the price path rises (upper right quadrant) and demand drops off (upper left quadrant). Note that the resource is never actually exhausted because there is a *backstop price* at which the "resource is said to be economically exhausted". However, the time to depletion is increased with use of EOR in mature oil fields. See Figures 1 and 6 from Gowdy and Julia. Presumably, substitutes are available at the point when production reaches the backstop price. The implications of all this for peak oil and current production behaviour are clearly explained by [Francis de Winter]() at hubbertpeak.com.

> The Harold Hotelling paper is often referenced because of its description of the "Free Market" mechanism by which our descendants are systematically deprived of any significant access to the finite natural resources which we currently have at our disposal.

> This mechanism works as follows.
>
> If one "owns" an oil well, one has to decide whether to "produce" (i.e. extract) and sell the oil now or later. If one produces and sells the oil now, one can put the money in the bank, and it will grow because of the interest it will earn. If on the other hand one produces and sells the oil later, one has to discount the money one will get for the oil, because one is getting the money later, and not now. With either way of looking at this, there is only an incentive to produce and sell later (rather than now) if one has the certainty that the oil in the ground is appreciating as fast as the money in the bank (in annual percentage rate), or as fast as the annual discount rate used in the operation one runs. Many operations (companies, etc.) use an annual discount rate of 10% or even larger.
>
> Consider an annual discount rate (or interest rate) of 10% and a 25 year-long generation. In 25 years, a compounded 10% annual interest rate will multiply an original investment by a factor of 10 (yes, ten), and an annual discount rate of 10% will decrease a later money receipt by a factor of 10. What does this mean? It means that an oil well owner using a discount rate of 10% has no incentive to leave any oil in the ground for our children 25 years from now unless there is a certainty of getting the children to pay 10 times as much for the oil as we are paying now, and our grandchildren 50 years from now would have to pay 100 times as much as we are paying now.

Finally, as Gowdy and Julia note, "theoretical [economic] models that address the issue of resource scarcity such as those of Hotelling and Ricardo assume 1) fully informed agents, 2) efficient allocation through time and 3) that present and future resource stocks are known". This quote is from section 1 of their paper, *The Economic View of Resource Scarcity*. I suggest you read that section--actually, I suggest you read the whole paper, it's quite good.

The Contentious Issues

Analysts like Michael Lynch, the IEA and others contend that Hotelling's rule does not apply to world oil production, principally because future resource stocks are not known [from Lynch].

> There appear to be two primary errors in the design of these models. First, Hubbert-style forecasts take URR as a static variable when it is dynamic. This is a serious error. URR refers not to total resources, which is arguably a fixed amount, but to the proportion of the total which is recoverable....
>
> Indeed, URR estimates do seem to expand by time, with the average estimate from the 1950s and 1960s being 1.0 trillion barrels or less, while recently, numbers are 2.5-3.0 trillion. Examining individual authors--to correct for methodological differences--also finds the same pattern. The USGS has increased their estimates of URR from 1.7 trillion in 1984 to 3 trillion last year. Even Campbell has raised his estimates by 150 billion barrels from 1991 to 1997, an amount greater than consumption during that period....

This is not the view of the peak oil community. Roughly speaking, the current view is that world conventional oil supply (including condensates and NGLs) is roughly 2.3 trillion barrels (+/- 10%) and if, say, 43% of that is recoverable, that leaves us with about 1 trillion barrels left to exploit. According to the Lynch Cornucopian model, the oil in place (OIP) resources are not known at present and URR is expanding over time due mainly to advances in technology (like EOR techniques or super deepwater drilling) and assumed price rises. Required and sufficient investment is presumed to follow inevitably given the magical efficacy of technology and price. On the other hand, peak oil modellers base their analysis on Hubbert Linearizations, the (P/Q)/Q graph using past cumulative production, the well known new discoveries trend and some roughly calculated (but still vague) depletion rate for the existing world resource base. Total P5 and P50 reserves (the *Qt*) in individual cases (fields, countries) is predicted and not simply asserted. The world *Qt* is based on the big picture. Stuart's latest number is 2.35 trillion barrels. Importantly, peak oil theory rests on *a posteriori* extrapolations for fields like Ghawar or Burgan based on cases where good data is available (Texas, the UK/Norway North Sea, etc.) wherein it is assumed that the well-attested past also predicts the future. This seems like a reasonable assumption.

A Scarce Resource? Current Oil Production Practice

I think that the Gowdy & Julia result--namely, that EOR technology is masking real scarcity in the future, that technology does not create higher URR in existing fields (with the exception of some cases like Weyburn) and that prices are in fact too low due to temporary supply boosts--would not be disputed by many in the Peak Oil community. In fact, current production practices seem to follow de Winter's assertion; oil companies (IOCs or state-owned) are pumping it out like there's no tomorrow to meet ever growing demand. This practice in turn has kept oil prices within "reasonable bounds". These prices are still relatively low despite 30%/year rises over the last few years. Arguably, the price should be much higher but since URR is not regarded as fixed and it is assumed that daily flows (in mbpd) can be increased almost indefinitely (eg. by CERA), there is every incentive to keep pumping the oil. Regarding Hotelling, the OIP and what is ultimately recoverable is not perceived to be appreciating in value at anything even close to the discount rate, so there is every reason to produce it. No sharp drop-off in production (like that seen in the UK/Norway North Sea) is anticipated for world production. In fact, there are lingering fears of a sharp *decline* in oil prices among OPEC, the IOCs and other producers. This seems absurd on the face of it but there it is.

So, the problem for the peak oil community is to convince the people and the policy makers that oil *is* a finite resource that should be treated as precious. Furthermore, prices should reflect this. If that were the case, we would have a better chance of a flatter depletion curve later and could, at least partially, solve the "Hirsch Gap" problem. However, at this point, a couple trillion (or more if you believe the USGS) barrels of oil is never going to perceived as a finite, scarce resource in the current timeframe in any case.

Hotelling Revised--An Immodest Proposal

Well, if world OIP and URR are not regarded as finite and scarce, what would change that view? If you trust peak oil theory, you might also believe that perceived P5 and P50 reserves, which are always going up as they did mysteriously for the OPEC countries in the 1980's, simply don't matter. What matters is *peak flows*, the oil that can produced on any given day (mbpd). Peak oil theory implies that there is a number, say 88/mbpd, that will come at some point and never be exceeded. There may be a great deal of supply fluctuation *below* that number but it is never exceeded-- this is the infamous *undulating plateau*. It is argued here that it is this *maximum flow* number that indicates scarcity because the available supply at some given point at time--the time of the peak--is finite and known, even if it is only known in retrospect. None of us know when that time will come but many of us are confident that it will be within a few number of years (at most by 2015).

Perhaps the Hotelling model of the economics of resource scarcity should reflect the peak production flows, rather than some too-far-in-the-future abstract assumption of a total finite OIP and URR number (though those of us in the peak oil community *do* make this assumption). Let's change the Hotelling equation a bit. [Editor's note: have you got that window with the Gowdy & Julia formulation of the Hotelling equation available?]

In that equation, the term **S** is the remaining (recoverable) stock and **q(t)** is the time path for resource extraction that maximizes the present value of the stream of net benefits from extraction. Further,

S(t) = -q(t), S(t) ≥ 0, q(t) ≥ 0, S(0) = So (S at time 0)

Suppose we make the following revisions.

S(t) = -f(t), S(t) ≥ 0, f(t) ≥ 0, S(0) = So (S at time 0)

where **f(t) = q(t,a(t))**
and **a(t) = the available flows (in mbpd)**

What is this re-formulation intended to capture? The term **f(t)** is the time path for resource extraction that maximizes the present value of the stream of net benefits from extraction on the *basis of current or anticipated available supply at every time t* (the term **a(t)**), not on the basis of the whole couple trillion barrels *Qt*. Thus, this different calculation reflects the scarcity and finiteness of the resource in question based on the available incremental flows. Like any such model, it is an idealization. It depends particularly on much more transparency in the oil business which allows reasonable predictions, rational agents and is meant to *promote efficient allocation* in oil production. Even if TOD readers take issue with my simple re-formulation of Hotelling--and I have *no doubt* you will rake me over the coals on this one--please consider it a discussion point. This is all it is meant to be.

The presumption here is that pumping all the oil you can all the time to meet rising demand is **not** an efficient allocation of the world's remaining oil supplies. Price is too low given the impending peak in available oil flows. We would not steal from future generations the resources they will need to live on (at least not as quickly). For example,

- If EOR has temporary recovery rate benefits but entails steep declines later, then maybe it's better in maximizing benefits in the longer run to not bother and use stripper wells instead.
- Rather than ramping up new fields (like Kashagan) up to their maximum daily production as quickly as possible, perhaps it maximizes benefits to get to and maintain lower production levels to maximize benefits over the longer term.

Calculations to maximize profit might consider that mature field X with reserves r is depleting at n%. Or field Y has just come online with an initial production p now which is expected to rise (on reasonable assumptions) to p+n next year. Or that new project Z has a 80% chance of coming online in timeframe t with an initial output of n. Etc.

In other words, we would live in a more rational world. Prices will be higher as they should be. Demand would have to adjust. Alternatives could be more efficiently developed based on real pricing. Perhaps, I repeat, *perhaps*, in a world like this, a precious scarce and finite resource like oil would not be wasted as it is now as we drive toward a Thelma And Louise cliff that most people refuse to recognize.