The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

The Tragic Consequences of the High Discounting of Oil Extraction

Posted by Dave Cohen on October 23, 2006 - 2:04pm
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[editor's note, by Dave Cohen] This is a 1st draft of an essay in progress. It is quite long, but I believe your patience will be rewarded upon reading it. I solicit your comments and criticisms. Any mistakes are, of course, my own.

Over the longest possible term, since 1870, oil prices have not reflected predictions made by economic theories of finite (fixed stock) non-renewable resources like conventional oil. Consider the following quote from On the Economics of Non-Renewable Resources by Neha Khanna, an excellent introduction to the subject.

> Economists add another dimension to this distinction between renewable and nonrenewable resources. Since economics is concerned with the allocation of scarce resources, for an economist non-renewable resources not only have a fixed stock, they are also in limited supply relative to the demand for them. Thus, old growth trees with life spans of as much as 1000 years while renewable by the common definition, may be classified as non-renewable by economists due to their relatively slow growth to maturity and few remaining stands....
>
> Similarly, while coal would be considered non-renewable by some, most resource economists would consider it renewable due to the vast remaining stock. At current rates of consumption of about one billion tons per year, it is estimated that there is enough coal to last approximately 3000 years. **From an economic perspective, there is no immediate coal scarcity simply due to its fixed stock. It is as if it were renewable. There is no scarcity rent associated with its extraction**.

This essay will ultimately argue for the startling hypothesis that what Khanna says regarding coal also holds for oil in the market and finally comment on the tragic near-term consequences for humankind of this false & misleading market signal.

In order to proceed, it is necessary to present an abbreviated introduction to the theory and terms of the economics of exhaustible resources. After that, the problem will be discussed along the lines presented in Should we worry about the failure of the Hotelling rule? by Tobias Kronenberg. In this 2nd section, more details of the economics will be presented. This section will also discuss *substitutes* for conventional oil—these are called *backstops* by economists. One goal here is to get economists and those concerned about peak oil on the same page.

A final section will defend the hypothesis that the scarcity rent for oil is zero or close to it because the recoverable reserves base is percieved as being inexhaustible due to unwarranted assumptions about reserves growth or the existence of perfect substitutes. This means that large discount rates are associated with conventional oil extraction and hence the oil price does not accurately reflect its real scarcity with respect to the cumulative consumption of an actually limited natural resource — approximately 50% of the recoverable conventional oil has been extracted, currently about 30 billion barrels per year are consumed (all liquids, mostly conventional oil) and the rate of consumption is rising exponentially. Given the existence of real constraints on the extraction (production) rate of conventional oil — about which the economic theories have nothing to say — the tragic consequences of this market failure are discussed in the final section along with a brief discussion touching on the nature of *human social discounting of the future*, which serves as an explanation for our self-defeating behaviour.

1. A Short Introduction to the Economic Theory of Non-Renewable Resources

The essential equation is given by Jeffrey A. Krautkraemer in Economics of Natural Resource Scarcity: The State of the Debate. The text below is from page 12 of that document.

> Three economic measures have been used as indicators of resource scarcity: price, extraction cost, and user cost. These three indicators are related through a basic first order condition for optimal resource extraction:
>
> (1) $P = Cq + \lambda$
>
> where
>
> P denotes the extracted resource price
>
> Cq denotes marginal extraction cost
>
> λ denotes the user cost
>
> The user cost captures the nonextractive economic cost of current depletion, including the forgone regeneration for a renewable resource and the forgone future use of a nonrenewable resource. It also includes any contribution of the resource stock itself to the net benefit of extraction--for example, a more abundant resource stock may decrease extraction or harvest cost.

The *user cost* λ is variously known as the opportunity cost, the royalty, the *shadow price* or the scarcity rent as defined below.

> **Definition 1** — *Rent is a form of income*
>
> The concept of rent as a payment for scarcity goes back to the Classical Economist David Ricardo who used "rent" to explain why land (when scarce) earns a form of income that

is best measured by its marginal productivity. Therefore the definition of scarcity rents would be the following:

> **Definition 2** — *Scarcity Rent is the rent that accrues to the owner of a natural resource just because it is scarce.*

According to the classical theory of Hotelling (1931), the scarcity rent for a exhaustible resource must rise over time at the rate of discount, which is taken in Hotelling to be equal to the interest rate *r*. It is necessary to discuss the discount rate at some length as defined here. The extension of this concept as concerns what the optimal *social rate of discount* should be will be discussed in subsequent sections.

> The basic principle of discounting is that a dollar received or paid next year is worth less than a dollar received or paid this year. For example, a dollar received this year may be deposited in a savings account earning, for example, 5 percent interest. On the one hand, at 5 percent interest, the dollar will be worth $1.05 the next year. Looked at from the discounting perspective, one dollar received or paid next year is only worth approximately $0.95 today [the *Net Present Value*]. The discount rate in this situation is 5 percent, the interest on savings accounts. Other market interest rates, such as interest on bonds or corporate portfolios, may be used as discount rates as well. Such rates are based on the private **opportunity cost** principle or private time preference.

In this case, if there is a fixed stock (amount) of a non-renewable resource *R*, and keeping in mind equation (1) above, Kronenberg states that

> The difference between resource price *P* and marginal cost *Cq* in this case, is not a profit in the economic sense. It is a `royalty', or the *in situ* value of the resource. The latter term is derived from Latin, meaning "in place", so it is the value of leaving the resource in place instead of removing it. Expressed in more common words, it is the **opportunity cost** *λ* of extracting the resource, because extraction now means that less extraction is possible in the future.... We thus can see that actually it is not the resource price which grows at the rate of interest, but the in situ value of the resource [as shown directly below].

So, adding the time dimension to our notation in (1), we see that price is a function of the opportunity cost and the marginal cost of extraction:

(2) $P(t) = \lambda e^{rt} + Cq$

The resource price in the time series *t* is the opportunity cost, or royalty — which is growing over time *t* at the discount (interest) rate *r* as expressed in the term e^{rt} — plus the marginal cost of extraction.

Pulling all this together, for the finite non-renewable resource *R*, there are three cases to consider —ignoring, for the time being, the marginal costs of extraction—

1. Under what condition would it be optimal to defer extraction of the resource *R*? Only if the price of *R* was increasing faster than the discount (interest) rate, thus making its *Net Present Value* less than its future value.

2. If the price of *R* is appreciating at less than the discount (interest) rate *r*, then the *Net Present Value* is greater now than in the future. Therefore, it is optimal to extract it now rather than later.

3. According to the Hotelling Rule, quoting from Khanna—

> In a competitive market where there are a large number of sellers, and each seller can sell any quantity at the going market price, each resource owner would be faced with the same options and would follow the same logic. The result is that in this market the quantity extracted will be such that resource price will rise at exactly [the interest rate] *r* per cent per year.... If it were to rise slower, resource owners would begin to sell off current stocks and the current market price would fall [#2 above]. If the resource price were to increase at a rate faster than *r* per cent per year, all owners of the resource would hold on to their stock, decreasing the current supply in the market, thereby inducing the current market price to rise [#1 above]. The equilibrium price trajectory for a non-renewable resource would, therefore, be rising exponentially as shown in Figure 1.

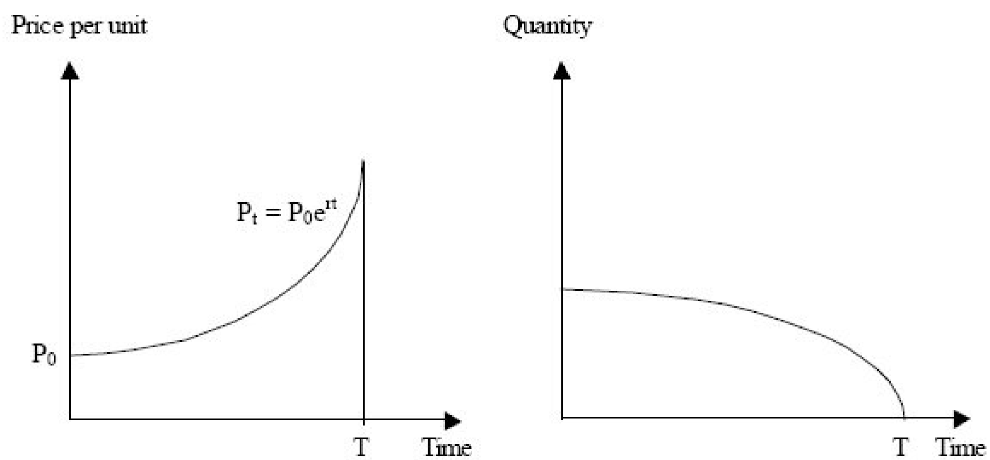


Figure 1: Equilibrium Price and Quantity Trajectories for a Non-Renewable Resource.
P_0 indicates initial price; T indicates complete depletion of the resource.

Figure 1 -- Click to Enlarge

Now, it is time to get back to reality.

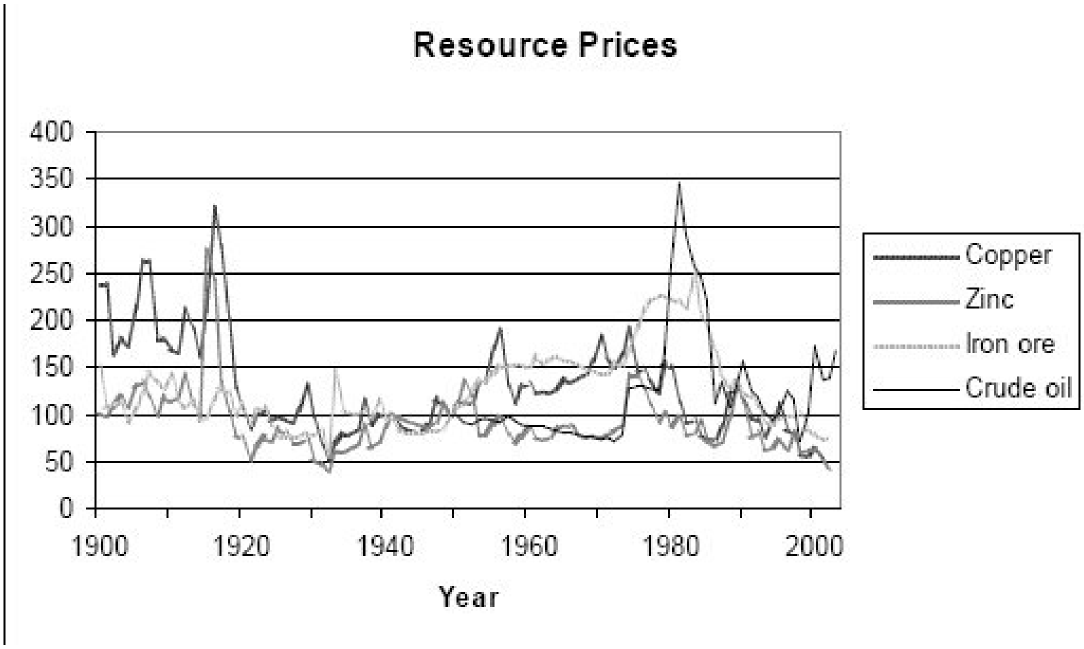
2. Examining the Failure of the Hotelling Rule

First, we must consider why the Hotelling Rule, when confronted with the empirical data, has failed for oil and other commodities. As presented in Kronenberg, "the evidence against the simple Hotelling rule is overwhelming." It is also very simple. Skipping the math—

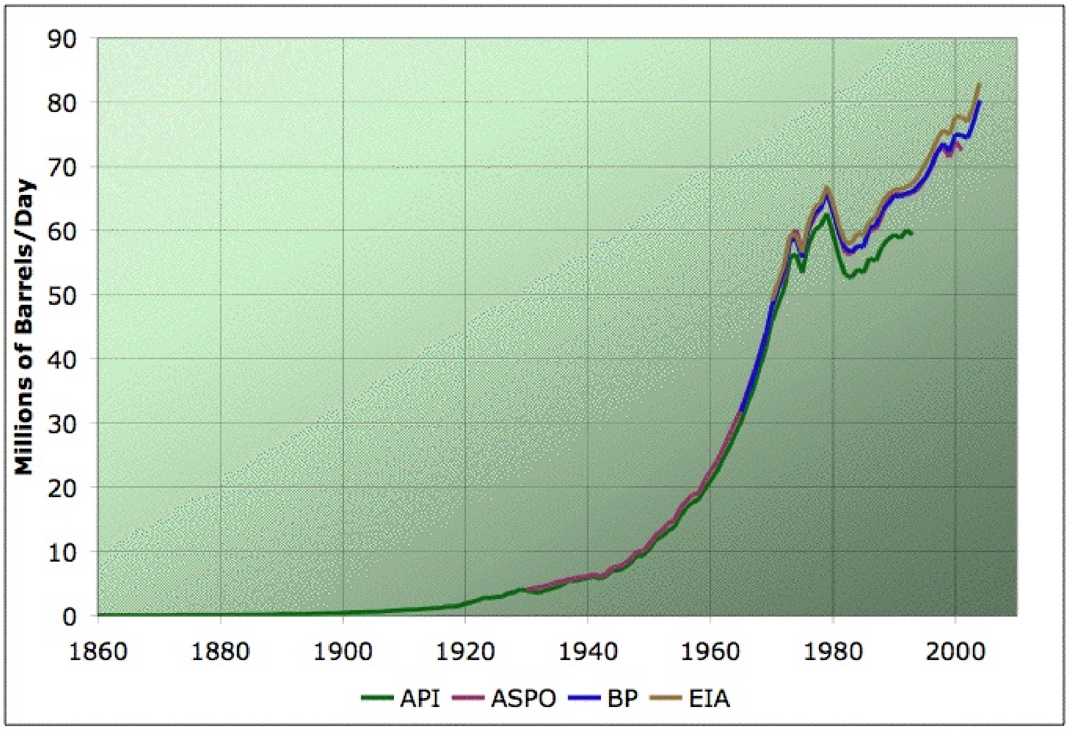
> Let us assume that there is a certain stock of a nonrenewable resource which can be used to produce energy. In period *t* an amount *E(t)* of the resource is extracted and transformed into energy [consumed]. The remaining deposit of the resource is *R(t)*...

> Assuming a demand function with a price elasticity of one ... it can be shown that the economy consumes a constant fraction of the remaining resource in each period. Let us call this fraction *C(R)*...
>
> [this tells us that] the remaining resource deposit will be falling at a constant rate, and this rate happens to be the consumption rate C(R)...
>
> Thus, since resource extraction [consumption] is proportional to the remaining deposit, it also falls at a constant rate.

However, over the course of the 20th century, resource extraction (consumption) grew over time and prices did not, as shown in figures 3 and 4 respectively.



Real price development of four major natural resources
The graph shows how prices of four major industrial resources evolved during the 20th century. All prices are adjusted for inflation and indexed with 1949 as the base year to allow for graphical comparability. For the most important resource, crude oil, we have information only from 1949 on. For three other resources, namely copper, zinc, and iron ore, we have information from 1900 on.
Figure 2 -- Click to Enlarge



Long time series of average annual oil production from various estimates. Believed to be all liquids, except API line which is crude only.
From Stuart Staniford's [Extrapolating World Production](#)
Figure 3 -- Click to Enlarge

The original simple Hotelling model makes many simplifying assumptions. Since it predicts rising prices and falling consumption over time, and in so far as just the opposite is true, Kronenberg considers extensions and additions to the model to try to bring it into accord with the empirical data. Some of these are discussed below.

Not every aspect of the economic theory could be covered. This essay assumes *perfect competition* and hence skips over considerations about monopolies (single versus multiple owners of the resource) and uncertain ownership of the resource. In the real world, the assumption of perfect competition may be viewed as reasonable for a fungible commodity like conventional oil. Ownership is an interesting question in its own right. For example, there has been a large shift in control of the resource from national oil companies to state-owned companies. This trend is particularly worrisome to the large consumers of oil among the OECD nations. But that is a subject for another time.

2.1 Marginal Extraction Costs

Hotelling (1931) does not include marginal extracton costs at all. Kronenberg, following Krautkraemer—cf. equation (1) above— adds a positive value for these as a constant cost, but notes that "resource prices should still be growing, albeit at a rate which is lower than the interest rate" as per equation (2) above. He then goes on to add—

> So far, we have assumed marginal extraction cost to be constant. This may be unrealistic. It is sometimes argued that there are **stock effects, i.e. the marginal extraction cost depends on the size of the remaining stock**. This can be the

> case in mining, for example, when the initial extraction takes place close to the surface, and over time the mines have to go deeper into the ground. The effect is that marginal extraction costs rise over time. Since the resource price is the sum of the in situ value and the marginal extraction cost, and the latter is not growing over time, prices must grow faster than under the simple Hotelling rule. Thus, stock effects in the form of rising marginal extraction cost are even more contradictory to the empirical evidence of constant or falling resource prices.

Much of Hubbert's original insight and the subsequent peak oil literature is subsumed by the economist as *stock effects* causing rising marginal production costs over time based on the *cumulative* production which steadily erodes the original reserve. These effects apply to old, large elephant fields like Samotlor, Ghawar, Cantarell, Daqing and Prudhoe Bay. Marginal extraction costs must rise because the per barrel costs remain the same as the production declines. Indeed, this costs rise more as improved oil recovery (IOR) techniques such as horizontal drilling are applied. Similar remarks apply to EOR techniques such as Nitrogen or CO_2 injection. The next section has more to say about this concerning deepwater extraction.

So, one can only agree that marginal extraction costs, as any oil company will tell you, are rising over time and will continue to do so. This is what is meant when someone says, speaking of oil production, that the "low-hanging fruit" is gone and that the era of cheap oil is over.

2.2 Technological Progress

The mainstay of the economist's viewpoint on why commodity consumption has risen while prices have not is technological progress. From Krautkraemer—

> The empirical evidence to date for natural resource commodities is largely in favor of technological progress. The many predictions of impending doom have not come true--at least not yet. The discovery and development of new reserves, the substitution of capital, and technological progress in resource extraction and commodity production have led to generally downward sloping price trends for many natural resource commodities. If there is any systematic bias to past predictions of the future, it is an underestimation of the ability of technological progress to overcome natural resource scarcity. For example, petroleum supply forecasts have persistently overestimated the future price of oil and underestimated oil production (Lynch 2002). The picture is less clear for the amenity goods and services derived from the natural environment.

The reference is to Michael Lynch's Forecasting oil supply: theory and practice. The fundamental insight, which Lynch and resource economists would defend, is that marginal extraction costs decrease over time due to technological progress which leads, in turn, to falling or relatively constant prices over time.

Consider the view of the World Energy Council in Deepwater Hydrocarbon Development in the New Millenium, written the the late 1990's, and *Figure 4*.

> A list of technologies which have been important in improving the efficiency of the hydrocarbon extraction industry to date would include the following:
>
> - Interpretation workstations capable of handling and visualizing large 3-D volumes
> - 3-D seismic data and advanced seismic processing

> - The use of seismic amplitudes for hydrocarbon and reservoir prediction
> - Methodologies for basin analysis and predictive stratigraphy
> - Magnetic resonance imaging for downhole logging
> - Tension leg wellhead platform (TLWP) and other smaller floating structures
> - Computer-controlled thrusters onboard dynamically positioned drill ships
> - Global positioning systems (GPS)
> - Automated pipe handling systems on drilling vessels
> - Geosteering for control of wellbore placement in the reservoir
> - Subsea systems
> - Horizontal drilling and well completions
>
> New technologies will help to further drive down the cost of finding, producing and transporting a barrel of oil in the future. New technologies can also increase the amount of oil recovered through improved exploration success, higher recovery factors and optimized well placement. Historically, new technologies have played an important part in reducing the average cost per barrel of finding and producing oil. [*Figure 4*] These lower costs increase profitability and government revenue and open up new frontiers in areas that were once prohibitively high-cost.

U.S. Oil Finding and Developing Costs
Figure 4 -- Click to Enlarge

The irony that U.S. oil production was falling during the entire time period shown in *Figure 4* will be skipped over at this point. Certainly, technology has made economic recoverability *possible* in continental shelf deepwater basins in Brazil, the Gulf of Mexico, the Gulf of Guinea (West Africa) and elsewhere, but it can not be argued that marginal extraction costs are decreasing. In a 2003 *Oil & Gas Journal* article *Worldwide finding and development costs on the rise*, cited by ASPO here, we read

> Although technological advances led to lower finding and development costs in the early 1990s, F&D costs have increased since 1997, Merrill Lynch analysts said in the May 29 report. Unless capital efficiency improves through renewed technology changes similar to those seen in the early 1990s, finding and development costs are likely to rise because of deteriorating returns within an aging resource base.
>
> "Companies have already captured most of the benefits from earlier breakthrough technologies in mature areas, and are now required to increase their maintenance capital just to maintain production levels from their established production base," the report said. Lower costs in emerging countries and the deepwater areas partially offset the struggle to replace reserves in mature areas, but companies are opportunity constrained in these lower-cost areas, analysts said. "After a dip in F&D costs in 2000, costs have risen even more dramatically in both 2001 and 2002"...

Costs are so high for *ultra*-deepwater production that it is not yet clear whether some fields like Jack in the Lower Tertiary Gulf of Mexico will be economic to develop at all.

Although technology has historically decreased marginal extraction costs, it is not now doing so and any recent downward price movements can not be attributed to this factor. Instead, in almost all cases, the impact of technology is to potentially increase the recoverable reserves stocks by making them economic to produce in the first place —a point to which we now turn our attention.

2.3 Reserves Uncertainty and Growth

Anticipating the conclusions of this essay, the considerations discussed in this and the subsequent sections dominate the reasons for the failure of the Hotelling rule. This section discusses *conventional oil* which is taken to be crude oil, condensates and natural gas liquids. Everyone agrees on the simple calculation shown in *Figure 5*. This is taken from the Center For Global Energy Studies Market Watch Report of July/August 2006. This report was critiqued by HO and further comments were made by the author responding to Dr. Leo Drollas, the chief economist at CGES.

Changes in oil reserves

=

[Discoveries + Extensions + Revisions]

- Oil production

Figure 5

The Hotelling model assumes that the total resource stock is finite and known with certainty. However, there is always uncertainty about reserves due to reserves growth (field extensions or revisions) and new discoveries as *Figure 5* shows. For example, Stuart Staniford uses a Hubbert Linearization to calculate the world's remaining stock (see the reference in *Figure 3* and arrives at these numbers:

- URR is 2250 ± 260gb (ultimately recoverable reserves)
- K is 4.93 ± 0.32% (world decline rate)
- the logistic peak is May 2007 ± 4.5 years

Kronenberg gives the resource economist's view of reserves here:

> If there are stock effects, exploration can lower the marginal extraction cost by increasing the stock of remaining resources.... In the long run, however, exploration opportunities are limited, and exploration will run into diminishing returns. As new discoveries become less frequent, the basic Hotelling intuition holds again, and resource prices rise again. Thus, allowing for exploration also generates the possibility of a U-shaped price development (Krautkraemer, 1998).
>
> However, **the existence of exploration opportunities will not go unnoticed, and will affect agents' expectations**. Such expectations will be formed about the frequency and size of new discoveries, and also about the total amount of resources that will be discovered. Exploration becomes then simply a costly activity which can be added to marginal extraction costs, and agents will base their decisions no longer on the known remaining reserves, but on the expected remaining reserves. Expectations will be revised whenever new information is revealed, which will generate some volatility and deviations from the Hotelling rule. **Nevertheless, the basic Hotelling intuition still applies, and the resource price must be increasing unless**

> **expectations are systematically incorrect**.

Bearing in mind Kronenberg's remarks, these *stock effects*—also known as *reserve dependent costs*—link the marginal extraction cost to the cumulative production which obviously affects the remaining stock (Khanna, page 6). These *stock effects* are indeed real as noted in section **2.1** above. In this case, the opportunity cost (scarcity rent, et al. λ) is taken to include modified extraction costs in addition to forgone interest income. In theory, it includes "any contribution of the resource stock itself to the net benefit of extraction--for example, a more abundant resource stock may decrease extraction or harvest cost" (as quoted in section **1.** above). Extensions to fields under production fall into this category. The converse could also be the case—a less abundant resource may increase marginal extraction costs. This is the case discussed in **2.1** for existing fields that have passed their peak of production.

If marginal extraction costs are rising due to *stock effects*, Hotelling predicts that the opportunity cost should rise at a rate less the percentage increase of extraction costs. But this is not observed in the historical price and consumption data. However, these real *stock effects* may be influencing the rise in price since 2002. Consumption, however, has not been affected (excepting the recent demand & price downturn) and the inflation-adjusted price is not at its all-time high.

The take home point is that reserves growth may be viewed as decreasing harvest costs. Does this account, in part, for the failure of the Hotelling rule? Here is what Kronenberg has to say—

> If new discoveries [reserves growth] are the reason for the Hotelling failure, there may be a problem if **expectations are not fully rational**. If new discoveries occur, people will form expectations about the total available stock of the resource. This is not a problem if expectations are rational. The market will then price the resource according to the expected total stock, and will adjust to any positive or negative realizations. But if expectations are not fully rational, there is a problem. Under optimistic expectations the rate of resource consumption would be consumed too high, and under pessimistic expectations it would be too low. In theory, therefore, the bias can go towards either direction.

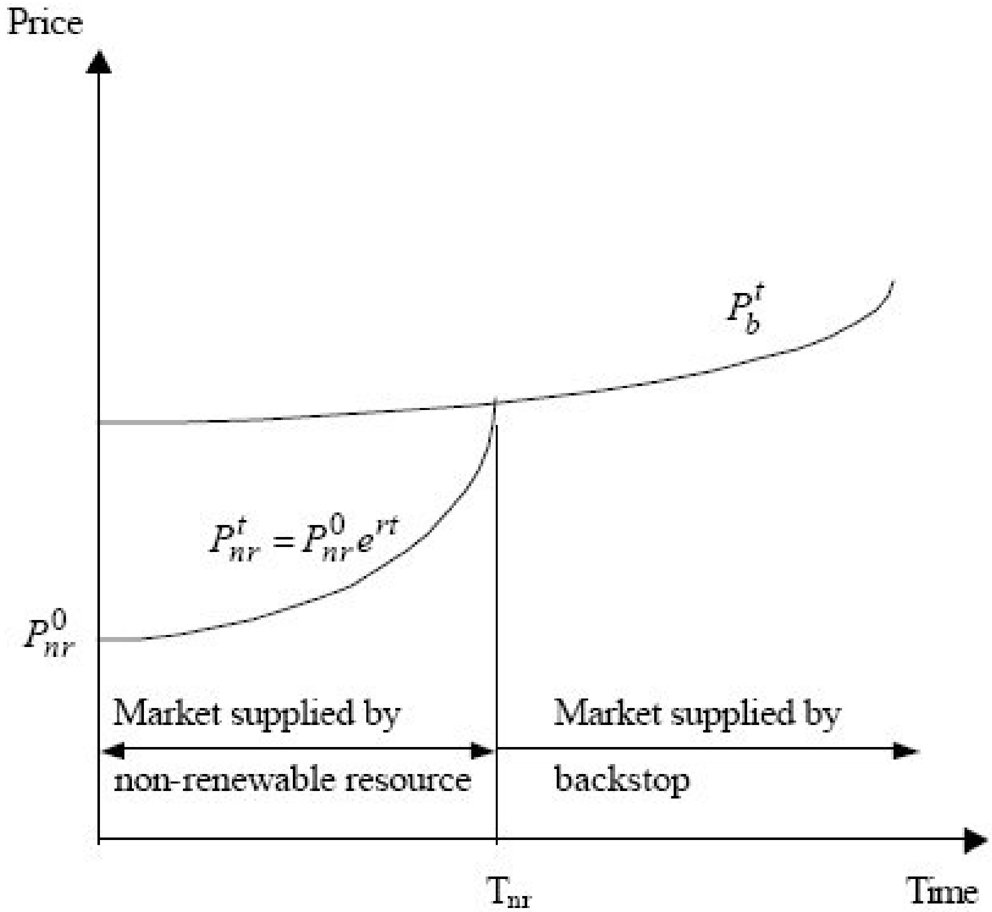
This is a **very important** point. When Robert Esser of CERA testifies before that

> In 1995-2003 global production of 236 billion barrels was more than compensated by exploration success and field upgrades that collectively added 144 billion barrels and up to 175 billion barrels, respectively

he is setting expectations that may not be "fully rational" because he is simply re-affirming something that all Cornucopians believe—reserves growth always outstrips consumption, despite the unacknowledged sharp observed decrease in newly discovered oil stocks. As Kronenberg says, the "rate of resource consumption would be ... too high". And this is what we observe in the world.

2.4 Backstops

A economic theory of finite non-renewable resources refers to a *perfect backstop*. This is more widely known as a complete *substitute* for the resource under consideration, which is conventional oil in this case. If such backstop exists, then Hotelling theory predicts that the price should rise according to *Figure 6* taken from Khanna.



Impact of Backstop Resource. Pnr indicates the price of the non-renewable resource; Pb indicates the price of the backstop. Tnr indicates the depletion of the nonrenewable resource.
Figure 6 -- Click to Enlarge

The fundamental insight is that the price rises and the remaining resource stock is all used up prior to the switch because the existence of a perfect substitute renders the resource worthless. In theory, when the price reaches the backstop price, all of the resource would have been consumed and substitution occurs. Therefore, the perception that perfect substitutes actually exist increases the extraction rate of the resource.

Do perfect substitutes for conventional oil exist? The answer is "No". There is no perfect backstop but there are a plethora of imperfect substitutes—that we might call *wedges*—that might replace some part of the role conventional oil plays. The very notion of a substitute for oil is fuzzy. Note that in the general case, almost any abundant source of hydrocarbons, regardless of considerations affecting their production, is percieved as a backstop for conventional oil. Here is a brief list of the main wedges.

1. Canadian tar (oil) sands
2. Orinoco heavy tar
3. Coal/Natural Gas/Biomass to liquids
4. Oil Shales
5. Electric transportation
6. Wind, Hydro, Solar and Nuclear to support #5

It is important to remember that when one hears hyperbole about any of these substitutes, it is not the case that any of these backstops is perfect because they don't scale or their net energy return is low (if not = 1) rendering them expensive —and in the worst case— uneconomic to produce. This is just a partial list. The current enthusiasm for ethanol from a corn feedstock (as opposed to Brazil's use of sugarcane) is a good case in point. The hyperbole leads to a false belief that the substitute under discussion is a perfect backstop for conventional oil. Kronenberg states that for both the resource owner *O* and the resouce consumer *C*, this can lead to what he calls *strategic interactions* that lead to serious market failures.

2.5 Strategic Interactions

Here is a description of the game that Kronenberg terms *strategic interactions*.

- The resource owner *O* knows the total stock of the resource. The resource consumer *C* does not.
- *C* has the option of developing a backstop technology at any time
- *O* can delay the development of the backstop by influencing *C*'s decision by lying about the stock of remaining resources

Here is the result as described by Kronenberg (page 25):

> Thus, if there are information asymmetries between the owners and consumers of a resource, strategic interaction takes place, and credible announcements play a critical role. Specifically, resource owners will have an incentive to overestimate the resource stock, so as to delay the development of substitutes for the resource. To make this announcement credible, they have to follow an extraction path consistent with the overestimated resource stock, so extraction will be faster than socially optimal. Resource consumers will have an incentive to announce the development of a backstop technology, and resource owners will react to this threat by raising the extraction rate and lowering the resource price (if the demand curve is downward sloping). **In both cases, resource extraction occurs faster than socially optimal**.

This interaction may be viewed as a reason for the failure of the Hotelling model. In fact, the suspicious OPEC reserves increases that took place in the 1980's is cited as a possible example and Kronenberg notes that resource (both national and state-run) owners have clear incentives to systematically over-estimate their remaining reserves which, in turn, leads to serious market failures. In order to manage consumer perceptions, extraction must remain higher than is socially optimal for a finite non-renewable resource in all cases.

3. Extraction Rates and High Discount Rates for Oil

Congratulations if you have made it this far. It is hoped that you will have a greater insight into the meaning of this IEA estimate (*Figure 7*) of available oil resources, which includes both substitutes as discussed above and conventional oil reserves. The graph indicates that there are approximately 5.5 trillion barrels of oil available as a function of price.

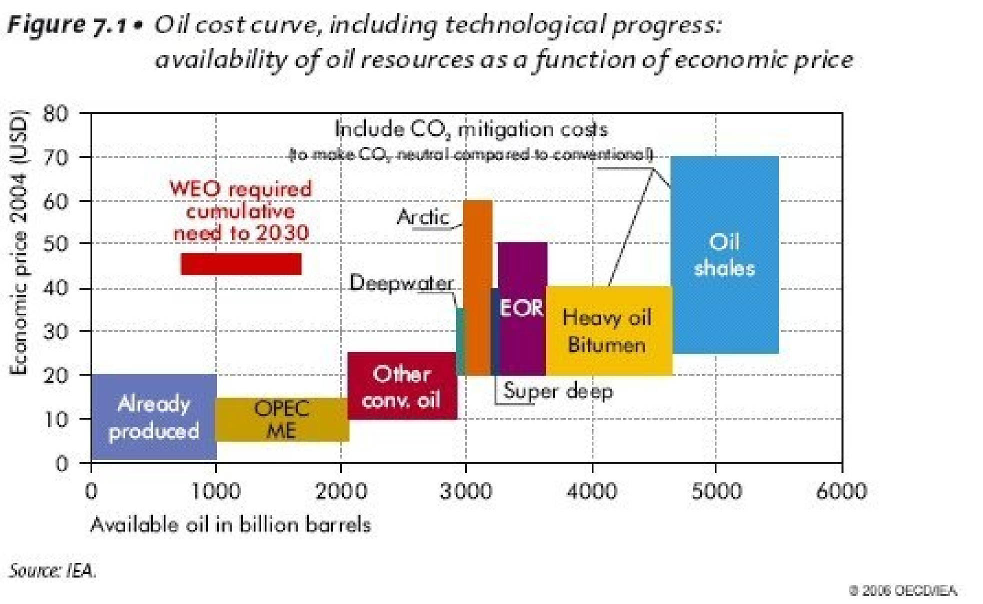


Figure 7 -- Click to Enlarge

Let us sum up. Here are the main findings

- resource extraction (consumption) has risen exponentially over time
- marginal extraction costs are rising
- *stock effects* are real but not reflected in price
- technology is no longer decreasing marginal extraction costs
- substitutes are perceived to exist and be perfect
- reserves are stated as — and perceived to be — always growing
- the Hotelling Rule has failed over time and price has not reflected any real scarcity

Under the economic theory of finite, non-renewable resources as first stated by Hotelling (1931) and considering further extensions to this theory that attempt to bring it closer to empirical reality, there can only be one explanation for the findings listed above. It must be the case that the opportunity costs (scarcity rent, et.al) of oil are percieved to be zero or close to it. This means, in effect, that oil extraction is heavily discounted, despite rising marginal extraction costs, because there is a perception that, for all intents and purposes, there will always be plenty of resources available in the future. This discordance between the compelling logic of the Hotelling model and the observed data means that the conventional oil resource is not being treated as finite and non-renewable.

Are the Cornucopians right? Is there nothing to worry about? Almost certainly not. The economic theory has nothing to say about geological (physical) constraints on extraction rates. For example, there are such contraints on additional production flows resulting from CO2 injection even though the stranded oil resource base is very large. Other examples abound—heavy oil in ultra-deepwater, the Canadian tar sands, etc. The theory does recognize *stock effects* that obviously apply to old existing elephant fields like Samotlor (Russia) or Ghawar (Saudi Arabia). However, this only affects the marginal cost of extraction, not its rate, in those fields. Technology is seen as lowering marginal extraction costs but what about real cost limits on applying technology for extraction? As HO (only half facetiously) said, in the worst case, you could dig a hole in the ground and mine for stranded oil. But what would the marginal costs per unit of output (barrel of oil) of doing that be? And what would the extraction rate be? Clearly, it would include the cost of fossil fuels inputs to the production of fossil fuels just like the use of natural gas to produce the tar sands of Canada. These costs provide an absolute limit on production if the Net Energy (considered in the widest possible sense regarding boundary issues) = 1 or is close to unity. The resource is not reasonable to produce at any price. But again, this constraint is not recognized. Therefore—and tragically—the theory can not make predictions about the timing of the peak of oil production because real constraints on outputs over time are not accounted for.

All of this has to do with the social rate of discount as described in Chapter 7 of Economic Valuation of Natural Resources (same link as for discounts above):

> In general, the application of discounting in a social value context incorporates the more complex concept of *social time preference* and is often very difficult to determine. The problem of measurement parallels that of market and non-market goods. The *private rate of time preference* [discounts] is revealed in markets, but the social rate is not. With respect to natural resources, the fundamental issue is one of defining a discount rate which reflects society's collective preferences regarding resource utilization or retention. The discount rate in the natural resource or environmental arena can be thought of as a measure of the opportunity cost of not having immediate access to a resource.

A fundamental problem is that human beings are inherently myopic; they exhibit "impatience" and tend *by nature* to value the present and discount the future. In fact, the entire edifice of Cornucopian thought regarding oil and its extraction may be thought of as a rationalization for the human tendency to discount the future and thus deprive future generations of access to the resource.

This insight is stated explicitly in this interview with Michael Perelman, author of The Perverse Economy: The Impact of Markets on People and the Environment.

> People are impatient; we don't like to have to wait for things. That's what road rage is often about, 'I want to get there quickly'. This impatience expresses itself in discounting....
>
> Discounting is supposed to be a reasonable way of doing things -- and this is what [Nobel Prize-winning economist Tjalling] Koopmans was saying about helium -- is because the economy is supposed to represent preferences. If these are our preferences, that's what value should represent, and the market should represent our values. But when you're dealing with resources, a fixed stock of irreplaceable resources, you can only run it down, you can't build it back up. Then this kind of thinking becomes destructive. And at present, there is no way that I can see of building a bridge to allow, say, the ecologist's understanding of resource scarcity in the future with the understanding of the economist for whom this discounting is second nature.

It is ironic that their evolution has set up *homo sapiens* to procreate and then nurture their offspring but, being shortsighted—which is expressed in their *social time preference* for large discounting of the future—can not see their way clear to support the viability of future generations by preserving resource for their use and allowing for substitutes to be developed.

For me, this is probably the dominant reason why the future often looks bleak and forms the foundation of why I have diminishing hopes about the whole notion of *Progress* and our prospects as a species.

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