ON THE ECONOMICS OF NON-RENEWABLE RESOURCES

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Contents

1. Introduction: Renewable Versus Non-Renewable Resources
2. The Hotelling Model of Resource Depletion
3. Variations on the Basic Hotelling Model
3.1. Extraction Costs
3.1.1. Exogenous Extraction Costs
3.1.2. Reserve Dependent Costs
3.2. Monopoly
3.3. Multiple Sources of the Resource
3.4. “Backstop” Resources
3.5. Growing Demand
4. On Discount Rates
5. Case Study – World Oil
6. Conclusions
Appendix
Acknowledgements
Glossary
Bibliography
Biographical Sketch

Summary

This paper presents an overview of the key economic results associated with the use of non-renewable resources. The basic Hotelling model of resource depletion is discussed, followed by several extensions. The fundamental result is that scarcity rent rises at the discount rate, and that, at equilibrium, marginal benefits from extraction must equal the marginal economic cost. If marginal extraction cost is determined by the remaining stock of the resource, then the result is that the scarcity rent rises at the discount rate less the percentage increase in marginal cost caused by the marginal reduction in remaining reserves. The versatility of the Hotelling model is clearly brought out in the various qualitatively distinct outcomes possible for the equilibrium production and price trajectories. Production may be monotonically increasing, decreasing, or inverted u-shaped. The equilibrium price trajectory is determined by the interaction between the marginal extraction cost and the scarcity rent. Typically, it is increasing throughout the production horizon. However, if the marginal cost is declining rapidly, it may exceed the scarcity rent in the early part of the production horizon and price will decline. Eventually, however, it must rise as scarcity rent rises sharply. The results obtained under the Hotelling model are robust to the assumption of market structure – both

monopoly and perfect competition yield qualitatively similar outcomes, though, of course, the price and quantity paths are different. The paper concludes with a case study of the global oil market, using a particular extension of the Hotelling model that is applicable in this case. Several qualitatively different scenarios are presented, each of which is consistent with the crude oil production and price trajectories observed since the early 1970s.

1. Introduction: Renewable Versus Non-renewable Resources

The New Webster's Dictionary defines "renewable" as "replaceable naturally or by human activity". Examples of renewable resources include trees and other plants, animal populations, groundwater, etc. In contrast, non-renewable resources are those that are not replaceable, or replaced so slowly by natural or artificial processes that for all practical purposes, once used they would not be available again within any reasonable time frame. Obvious examples are oil and mineral deposits.

Economists add another dimension to this distinction between renewable and non-renewable 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. They may also be ecologically unique and not reproducible. Similarly, while coal would be considered non-renewable by some, most resource economists would consider it renewable due to the vast remaining stock. It is estimated that at current rates of consumption of about one billion tons per year, 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.

Traditionally, the major economic issues in the study of non-renewable resources have involved predicting the future production and price trajectories, as well as the date of possible resource exhaustion. In addition, there has been an effort to understand the impact of alternative market structures, such as pure competition, monopoly, and a cartel-dominated oligopoly, on the predicted trajectories. More recently, the environmental costs associated with the extraction and consumption of non-renewable resources have also come into focus.

2. The Hotelling Model of Resource Depletion

The central question in non-renewable resource economics is: given consumer demand and the initial stock of the resource, how much should be harvested in each period, so as to maximize profits? A simple example brings out the underlying intuition. For now, assume away any extraction costs and focus on the price per unit, p, of the resource in the market. Assume also that the real (inflation adjusted), risk-free interest rate on investments in the economy is r per cent per year. Then, the owner of the resource can either extract the resource now or hold on to it to extract in the future. Any amount of the resource extracted today will not be available in the future, and any resource left untouched today may fetch a higher price in the market in the future. These are the two fundamental factors influencing the resource owner's extraction decision. If the owner extracts the resource today she can invest the proceeds and earn r per cent year. However, if she expects the price of the resource to rise faster than r per cent per year, then it would make sense to hold on to the resource, forgo the interest earned on the proceeds but earn a higher total income by selling the resource at a higher price per unit. The opposite argument would hold if the resource price was expected to rise slower than r per cent per year.

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 theoretical result is that in this market the quantity extracted will be such that resource price will rise at exactly 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. 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. The equilibrium price trajectory for a non-renewable resource would, therefore, be rising exponentially as shown in Figure 1, where P_0 is the initial price and T indicates the time period of resource exhaustion.

An implication of the continuously rising price is that the quantity extracted would be continuously falling until such time as the resource is exhausted. As the price rises the demand for the resource is slowly choked off. Eventually the price would be so high that demand would be eliminated altogether. In the basic model, this is precisely when the resource stock would also be completely exhausted. To understand why, suppose that when the price is sufficiently high to choke off entirely all the demand, resource owners are left with some positive quantity of the resource. This remaining stock would be completely worthless to the owner since no one would want to buy it. Realizing this, the resource owners would begin to sell off the stock at lower prices before the demand is choked off by the high prices. However, this would mean that there would be an excess supply of the resource in the market which would lower current prices. The production trajectory would be extended in time and again the price would continue to rise at r percent per year until all the stock is completely depleted. The equilibrium production (or extraction) trajectory for a non-renewable resource is also shown in Figure 1.

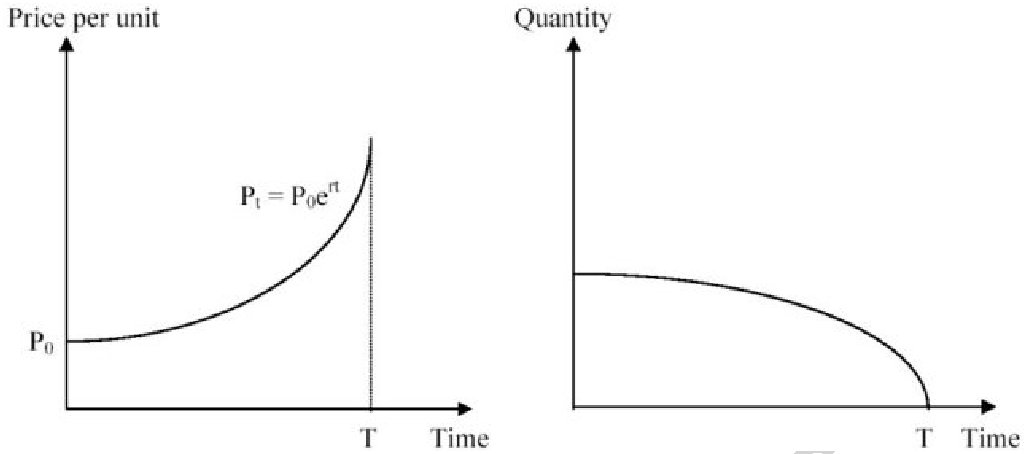

Figure 1: Equilibrium Price and Quantity Trajectories for a Non-Renewable Resource

This basic result that the price of a non-renewable resource in a competitive market would rise at the interest rate and that the production trajectory would be monotonically declining till the resource is exhausted was established by Harold Hotelling in his seminal 1931 article, “The Economics of Exhaustible Resources” published in the *Journal of Political Economy*. Few papers in economics have played such an important role in defining the field and contemporary research. It was the focus of Robert Solow’s 1973 Richard T. Ely lecture titled “The Economics of Resources or the Resources of Economics”. On the fiftieth anniversary of the publication of Hotelling’s paper, Shantayanan Devarajan and Anthony Fisher wrote a paper in the *Journal of Economic Literature* effectively showing that a large number of questions on the economics of non-renewable resources being asked today were first raised by Hotelling.

It can be shown that by following the above production trajectory the resource owner maximizes the present value of the flow of revenues from extraction over the time horizon from the present through the exhaustion of the resource. It can also be shown that the same production trajectory maximizes the discounted sum of producers’ and consumers’ surplus in a competitive market and is, therefore, Pareto optimal.

3. Variations on the Basic Hotelling Model

3.1. Extraction Costs

3.1.1. Exogenous Extraction Costs

Extraction costs per se do not change the fundamental logic of the above model. Suppose that the marginal extraction cost is slowly rising over time. This could be because a larger quantity of resources is being extracted in each period or due to more stringent environmental policies requiring more expensive extraction techniques, or both. Whatever the reason, so long as the marginal extraction cost is not determined directly by the *cumulative* amount of the resource extracted, the result would be that net price, i.e., price minus the marginal extraction cost, or scarcity rent, would rise exponentially at r per cent per year.

It is important to note that even though Hotelling's model of resource depletion implies that net price would be rising exponentially at the interest rate, this does not mean that the market price (i.e., the price paid by the consumer) will follow this trajectory. The consumer price is the marginal extraction cost plus the scarcity rent. If extraction costs are falling, say due to technological improvements as in the case of the oil industry during the last decades of the twentieth century, then it is entirely possible that the market price is constant or even declining in the near term. So long as the downward pressure due to the falling marginal extraction cost outweighs the rising scarcity rent, the consumer price will be decreasing. Eventually, however, as the resource gets depleted and the scarcity rent rises rapidly and outweighs the marginal cost, the market price will rise.

When the marginal extraction cost is rising over time, the equilibrium production trajectory is monotonically declining, as in the simple case with no extraction cost. However, if the marginal extraction cost decreases with time, then it is also possible for the equilibrium quantity trajectory to increase in the near term. During this period, the downward pressure of the falling marginal cost more than offsets the rising user cost.

3.1.2. Reserve Dependent Costs

A more sophisticated theory of non-renewable resource depletion would link the marginal extraction cost directly to cumulative production or the remaining stock of the resource. These are referred to as "reserve dependent costs" in the literature. In this case, each unit of the resource extracted today is not only unavailable in the next period, but also increases future extraction costs by lowering the remaining reserves. The opportunity or user cost of extracting a finite stock of resources is now two fold: foregone interest income and higher extraction costs. In this case, the scarcity rent does not rise at the interest rate, but at the interest rate less the percentage increase in cost due to a marginal reduction in remaining reserves.

Note that the basic principle remains intact: at equilibrium, the marginal benefit from extraction must equal the marginal economic cost (defined as the sum of marginal extraction cost and the user cost). In the case with no or constant extraction costs, or with extraction costs that vary independently of cumulative production, the economic cost of extraction is just the foregone interest income. With reserve dependent costs, one must include the increase in marginal extraction cost that occurs as remaining reserves are drawn down by current extraction.

3.2. Monopoly

The fundamental results of the Hotelling model remain unchanged when the entire stock of the resource is owned by a single seller. In this case it is the marginal profit or the difference between the marginal revenue and marginal extraction cost that grows at r per cent per year. However, if in the presence of a static demand curve the price elasticity of demand decreases as the quantity extracted increases, the monopolist's production trajectory will be longer than that of the competitive resource owner when faced with identical costs, initial stock, and consumer demand. The monopolist takes advantage of the relatively lower price elasticity in the earlier periods to restrict output and charge a higher price than the perfectly competitive resource owner.

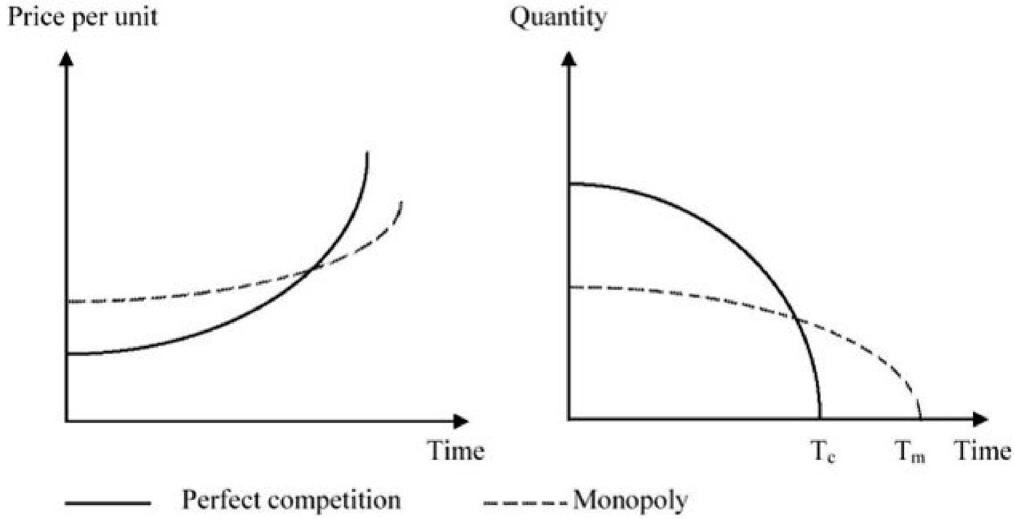

Figure 2: Monopoly vs. Competitive Equilibrium Price and Quantity Trajectories

The result is that the extraction path tends to get stretched out over time – that is, monopoly slows the depletion rate. This result has led to the adage, "a monopolist is a conservationist's best friend". The monopolistic and competitive price and quantity trajectories are compared in Figure 2, where T_c and T_m indicate exhaustion under competition and monopoly, respectively.

One case where the competitive and monopoly equilibrium price and extraction paths are identical is when the resource owners face a constant elasticity demand curve that is unchanging over time, and when the extraction cost is independent of the quantity extracted in each period. The crucial feature of a constant elasticity demand curve, as opposed, say, to a linear demand curve, is that total revenue is the same at all points on the curve. No matter how much the monopolist raises the price of the resource, quantity demanded declines proportionately so that total revenue is constant. In this case, the monopolist cannot increase the present value of profits by restricting quantity and raising price in the earlier periods.

3.3. Multiple Sources of the Resource

Another interesting extension of the Hotelling model considers the situation where there are two sources of the same non-renewable resource but with different marginal extraction costs. An example would be the oil deposits in the Southwestern USA and Alaska, and the deposits in Saudi Arabia. Both regions are endowed with vast quantities of crude oil.

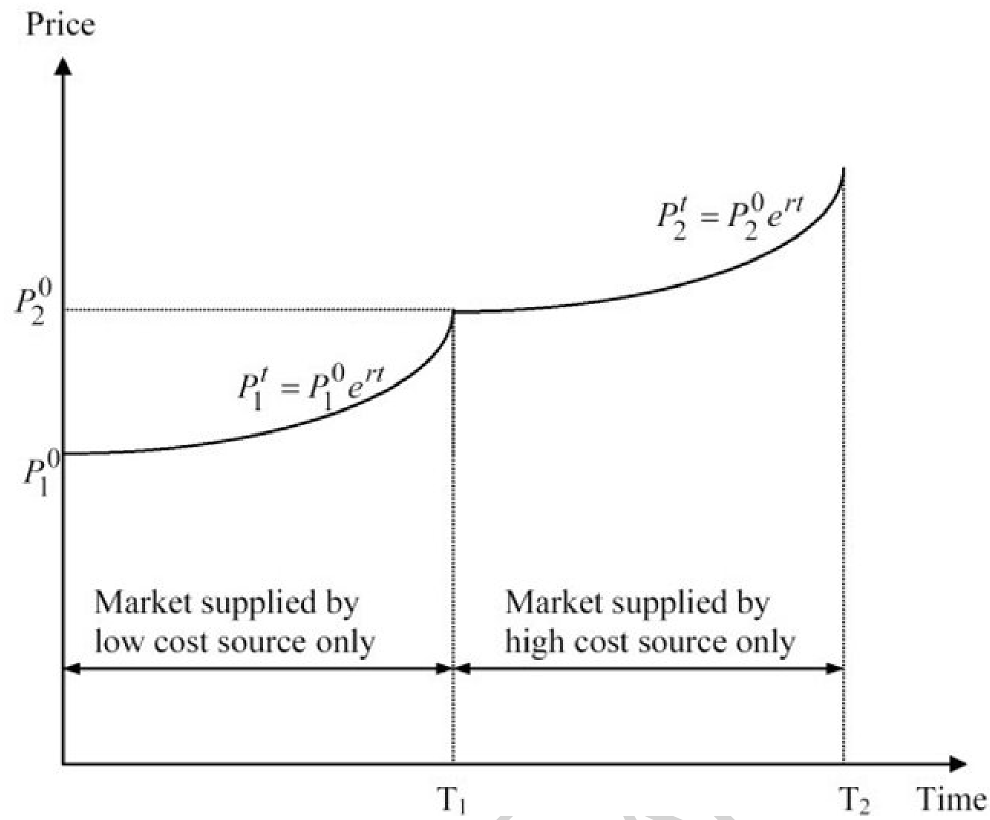

Figure 3: Equilibrium Price Trajectory with Multiple Sources

However, mostly due to geological differences, per barrel extraction costs in Saudi Arabia are about a quarter of those in the US. In the abstract world of perfect competition, both sources would not supply the resource simultaneously. Like David Ricardo's argument for using higher grades of the resource – or in this case, lower cost mineral sources – first, production would begin in the low cost region. The net price would rise at the interest rate until it is exactly equal to the net price for the second, high cost source. At this point, the low cost resource is completely depleted and the high cost source supplies the entire market. Scarcity rent would rise again at the interest rate till the second resource is exhausted as well. This succession of equilibrium price trajectories is shown in Figure 3, where P_1 and P_2 indicate the net price of the resource from the first and second sources, respectively, and T_1 and T_2 indicate the exhaustion of the two sources.

3.4. "Backstop" Resources

Suppose there is some other resource which is a perfect substitute for the non-renewable resource in question. Suppose also that this alternative, or "backstop" resource can be supplied at some high cost but in fairly large quantities so that it is inexhaustible for all practical purposes. Since the backstop has a virtually unlimited supply, its price will be just sufficient to cover its marginal extraction cost.

Implicitly, backstop technologies are assumed to be renewable. Ethanol fuel from renewable corn and sugar is frequently seen as a backstop for petroleum. However, a backstop technology can itself be non-renewable. For example, coal-based electric transportation would itself be a non-renewable backstop for finite petroleum resources. In the presence of a backstop, there is a ceiling on the net price of the non-renewable resource. In theory, as soon as the price of the non-renewable resource just exceeds the price of the backstop, the former will be priced out of the market and the demand would be entirely satisfied by the latter resource. (In effect, the price of the backstop is like the vertical intercept on the linear demand curve for the non-renewable resource.) The overall result is the same as in the case with multiple sources of the same non-renewable resource. The net price of the non-renewable resource will rise at the interest rate till it is completely exhausted. Exactly at that instant the net price would be equal to the price of the backstop and production would shift from the non-renewable to the backstop resource.

It is easy to argue that in the absences of a backstop, the non-renewable resource would be depleted at exactly the time when production shifts to the backstop. Suppose this is not the case and there are some remaining reserves of the non-renewable resource when its price rises to that of the backstop. Then the resource owner would be unable to sell the resource on the market since the net price necessary to cover the scarcity rent would exceed the price of a cheaper substitute. The only option is to sell the resource at an earlier and lower price. However, this would increase the supply in the market and the net price would fall. In fact, the price would decline to a level such that when it rises at the interest rate the resource is exhausted at the price of the backstop. A similar argument emerges in the situation where the resource is exhausted before its price reaches the ceiling set by the backstop. In this case, there is a large excess demand which would bid up the price for the resource. The profit-maximizing resource owner would then hold back some reserves to sell at the future higher price and the production horizon would be extended.

The above example assumes the supply curve for the backstop is horizontal at a price just sufficient to cover its marginal extraction cost. This assumption is not necessary. It is entirely possible that the price of the backstop is rising slowly. As long as the backstop price is rising slower than the interest rate, then the price trajectories for the non-renewable resource and the backstop will intersect at some point. At that point, the price of the backstop will become the ceiling for the price of the non-renewable resource and the latter resource will be completely depleted. From that point on, the market will be completely supplied by the backstop. Figure 4 shows the intersection of the price trajectories for the non-renewable and backstop resources, where P_{nr} indicates the price of the non-renewable resource, P_b indicates the price of the backstop, and T_{nr} indicates the depletion of the non-renewable resource.

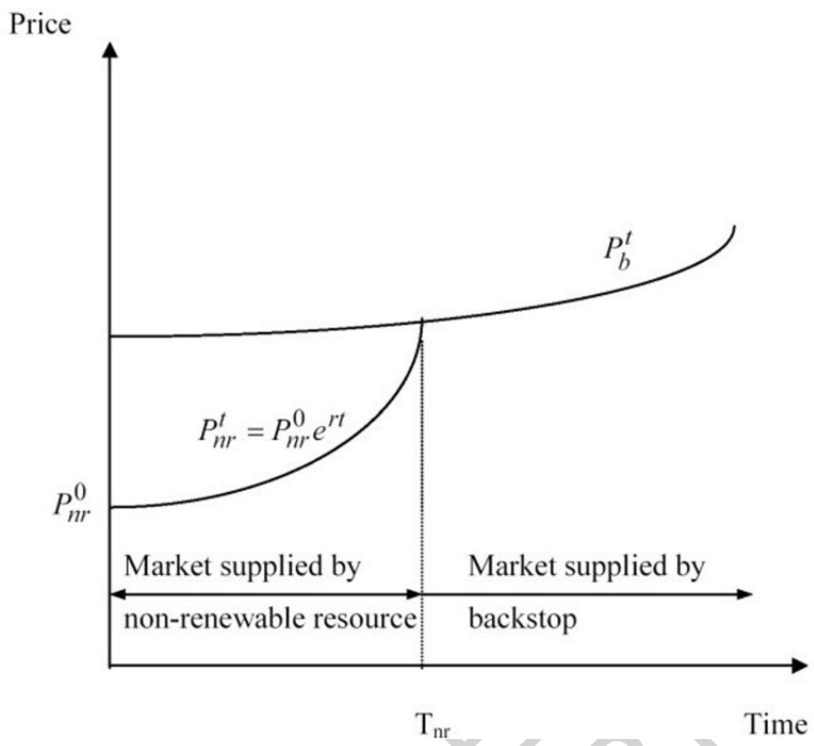

Figure 4: Impact of Backstop Resource

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Biographical Sketch

Neha Khanna was born in New Delhi, India. For the first few years of her life she traveled the length and breadth of the country with her parents, moving to a new location every few months. She finally settled in New Delhi, where her family continues to live.

Neha took her first economics class in grade eight, and never looked back. After graduating from high school, she joined St. Stephen's College, Delhi University, to pursue a B.A. in Economics. She moved on to obtain a Master's in the same subject from the Delhi School of Economics, Delhi University. For the next two years she worked as a Research Associate with a group of social and physical scientists at the Tata Energy Research Institute, New Delhi. It was here that her interest in the economics of environmental and resource issues was initiated.

She obtained a Ph.D. in Resource and Environmental Economics from Cornell University in January, 1998. Her dissertation is titled "Global Warming, Energy Use, and Economic Growth". She is currently Assistant Professor of Economics and Environmental Studies at the State University of New York at Binghamton. Her research focuses on the relationship between economic growth and climate change, resource depletion, and air pollution, as well as the socio-economic implications of voluntary pollution prevention programs.