ECONOMIC FACTORS IN THE
LONGEVITY OF RESOURCES

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Abstract

Resource owners, wishing to maximize the present value of their resource, will be influenced by a wide variety of economic factors. The economic analysis presented suggests that the following factors tend to increase the life of resources:

- a fall in the interest rate
- an expected rise in future prices
- an expected fall in future costs
- removal of import quotas
- prorationing
- monopolization
- removal of severance taxes and royalty payments
- imposition of property taxes
- severance subsidies and percentage depletion allowances
- unitization of reservoirs
- rising costs of exploration
- abolition of "rules of capture."

A present-value maximization model is also presented which indicates the impact of interest rates on life of resource, rates of recovery, and optimal ratio of reserves to output.
Introduction

The projected period of exploitation of oil, gas, and geothermal resources depends on geological and geophysical estimates of reservoir characteristics and capacity. It also depends on engineering management concepts which affect, among other things, recoverability and cost functions. Economic considerations enter the picture when, given an estimate of recoverable resource quantity (and quality) and the engineer's most efficient technology, the firm must make decisions concerning the lifetime of the resource and the annual rate of production.

Even renewable resources, such as timber and fish, are exhaustible and nonrenewable resources themselves can have infinite lives if production rates are reduced sufficiently: "monopolistic exploitation of an exhaustible asset is likely to be protracted immensely longer than competition would bring about or a maximizing of social value would require" (Hotelling, 1931, p. 152).

If it is economically feasible to exploit a resource, the period of exploitation will be affected by a number of economic factors. In the discussion below, the role of the following variables in the lifetime of oil, gas, and geothermal resources will be presented:

- the rate of interest or discount rate
- future prices and costs
- monopolization, import quotas, and prorationing
- rules of capture and unitization
- severance taxes and royalty payments
- property taxes
- depletion allowances,
1. The Rate of Discount (or Interest)

The market rate of interest is the price (per $ hundred) at which business firms can borrow or lend. In a perfectly competitive capital market under conditions of certainty these two rates are the same, but otherwise the borrowing rate is greater than the lending rate. For example, it is not atypical for a firm to have to pay 12-15 percent interest on borrowed funds and to obtain only 7-8 percent on funds lent without risk. Part of this difference can be attributed to risk and much of the rest represents the profit markup of professional lenders.

The rate of discount for a strongly-financed firm in a riskless investment will be close to the market rate of interest for lending, e.g., 7-8 percent. Such a firm does not necessarily need to borrow outside funds for its capital investments. The rate of discount for firms lacking internal funds will be closer to the borrowing rate of interest for moderately risky investments. For both types of firms the rate of discount will increase with increasing riskiness. If the degree of risk is held constant, the rate of discount will decrease when market interest rates fall, and vice versa.

The general effects of a lowering of interest (discount) rates are:

- a lengthened period of exploitation (Herfindahl, 1967, pp. 67-8)
- a lower annual rate of production (Scott, 1967, p. 31)
- a shift toward more production in the future (McDonald, 1967, p. 282)
- a greater ultimate recovery (McDonald, 1967, p. 282).

Strongly-financed firms have a lower rate of discount than firms which must rely on borrowed funds and will plan on longer operating lives for their resources (Gaffney, 1967, p. 352). The steam-suppliers at The Geysers field in California would no doubt prefer higher production rates and a faster payout period than is the case with Pacific Gas and Electric: "It costs
about $14 million to erect a 110,000-kw generating plant, and conservative utility managements do not commit funds of that size unless assured of sufficient steam to run the plan for at least 30 years" (Loehwing, 1973, p. 21). As indicated by one analyst of energy economics, "the strong firms arrive at higher R:O [reserves to annual output ratios]. It is an industry truism that weaker firms are more concerned with rate of recovery, and stronger firms with holding reserves" (Gaffney, 1967, p. 352).

The Gaffney Model

The impact of the rate of discount can be illustrated by the Gaffney model of optimal exploitation of natural resources (Gaffney, 1967, pp. 348-52). Given an estimate of the physical quantity (Q) of a resource in a particular location and a desire for steady annual production, the producer will determine the economic life (L) of his deposit by maximizing (over all possible lifetimes) the present net value of the resource.

Annual production will be a constant \( \frac{Q}{L} \) and the present value of revenues (PVR) is given by

\[
PVR = \frac{Q}{L} \left( \frac{1}{1+r} + \frac{1}{(1+r)^2} + \ldots + \frac{1}{(1+r)^L} \right) = \frac{Q}{L} \frac{1-(1+r)^{-L}}{r},
\]

where \( r \) is the rate of discount.

A general (although simplified) cost function can be obtained by assuming that doubling of life cuts costs in half because only half as much capacity is required. If the present value of the cost of extracting the entire resource in one year \( (L=1) \) is denoted by \( K \), the present value of costs is

\[
PVC = K/L.
\]

Maximization of present net value \( PNV = PVR - PVC \) requires the maximization of the following expression:
Given the cost \( K \) of exhausting the resource in one year and the rate of discount \( r \), various values for lifetime of resource (from \( L=1 \) to \( L=100 \), for example) are inserted in equation (3). That value for \( L \) is chosen which maximizes present net value.

If it is expected that 1,000,000 units of a resource can be extracted at a constant (normalized) price of $1.00 per unit, and if \( K \) takes on a value of $800,000, then the optimal lifetime of the resource is 7 years when the rate of discount is 5 percent. Present net value is $712,601 with annual production of 142,857 units. The half-life of the resource is 3.5 years and the optimal reserve-output ratio is therefore 3.5 (Gaffney, 1967, pp. 351-2).

On the other hand, if the rate of discount rises to 25 percent, the optimal lifetime falls to 4 years and the present value of the resource drops to $390,400. Annual production increases to 250,000 units and the optimal reserve-output ratio becomes 2:1.

In summary, higher rates of discount result in increased annual production, shortened periods of exploitation, and lower reserve-to-output ratios. A corollary of these results is that a government loan-subsidy program to weakly-financed firms would have beneficial effects on the lifetime of their resources.

2. Future Prices and Costs

Ordinarily an optimizing business firm will push production to the point where marginal profits become zero (Cummings and Burt, 1969, p. 985). In resource economics, however, the fundamental optimization principle is that production is pushed to the point where marginal profit in one time period is equal to the discounted marginal profit of the next time period. A necessary
condition for maximization of the present net value of a resource with a given
lifetime is

\[(4a) \frac{R_t - C_t}{(1+r)^t} = R_0 - C_0,\]

where \( r \) is the rate of discount, \( R \) is marginal revenue, \( C \) is marginal cost,
and \( 0 \leq t \leq L = \) given lifetime of the resource (McDonald, 1967, p. 279).

If the marginal net discounted return is not the same in every year of
the resource's life, then profits could be increased by shifting production
from one year to another (Herfindahl, 1955, p. 131). The present value maxi-
mization condition can also be expressed as

\[(4b) R_t - C_t = (1+r)^t (R_0 - C_0).\]

Equation (4b) indicates that, in the optimum time distribution of
production, marginal net income must increase at a percentage rate equal to
the rate of discount. This requirement means either

1. expected prices must increase over time, or
2. current production must be pushed closer to capacity so that current
   marginal costs of production exceed future marginal costs of production.
Marginal costs can be expected to rise rapidly as production is pressed closer
to capacity (McDonald, 1967, p. 276).

If a technological advance is expected \( t \) years hence, marginal costs will
drop in year \( t \) and thereafter and equation (4b) will be satisfied only if
production in these later years is increased. The resulting increase in
production will cause marginal costs to rise until the point is reached where
marginal net discounted values are again the same in all time periods.

It is possible that exploration using present technology is more costly
than future exploration using superior techniques (Gaffney, 1967, p. 231).
Nevertheless, there are some indications that real exploration costs (in
constant dollars) are rising in the petroleum industry. Although the percentage of new field wildcats that find oil and gas has remained relatively constant (at 11 percent), wells have been increasing in depth with costs per foot an increasing function of depth itself, and there has been a slight decline in average size of fields (Campbell, 1964, p. 117).

Rising real costs of exploration will tend to shift long-run marginal cost curves upward with a resulting increase in price and decrease in annual demand. The life of a given resource property will be lengthened, but the total stock of properties will decrease (Herfindahl, 1955, p. 134). For these conclusions to be valid, however, it must be assumed that superior technology will not become available in the future.

If it is suddenly expected that future prices will decline, it will pay the firm to shift production toward the present. If future prices are expected to rise, contrarily, production should be shifted toward the future.

The role of future prices can be exemplified in the context of the Gaffney model (with Q=100, K=150, r=.20). If price in every time period is expected to be $1.00 per unit, present value is maximized with a lifetime of 6 years and annual production of 16.67 units. If prices are expected to rise 10 percent a year, optimal lifetime is 8 years with annual production of 12.5 units. If prices are expected to rise 20 percent a year, it pays more in the long-run to hold the resource as a reserve than it does to currently produce any amount at all.

That nonproduction might be more profitable than production is likely a surprising result. However, if geothermal steam, for example, is worth $1 a unit and it costs another dollar to raise it, the wellhead price is $2 a unit. If the price at the wellhead is increasing 10 percent a year and there is no change in the cost of raising it, then the value of the steam in the reservoir
will be increasing 20 percent a year and this would be sufficient incentive for the geothermal owner-operator to withhold his resource from current production (Vickrey, 1967, p. 317).

3. Import Quotas, Prorationing, and Monopolization

Until recently the United States crude oil industry operated under state production restrictions which have been termed the allowable or prorate system (Gaffney, 1967, p. 371; Davidson, 1963, p. 85). The system which has been used by Texas is a fairly typical prorationing scheme. An estimate is made of the market demand for crude oil at the current price. From this amount are subtracted expected imports and production from old marginal wells ("stripper wells") which require considerable mechanical pumping in order to bring the oil to the surface. What is left over is allocated to the lower-cost wells which operated during much of the 1960's at production levels which were far below capacity. The number of day's production allowed for controlled wells in Texas fell from 345 to 97 days over the period 1947 to 1962 (Kahn, 1964, p. 300). Prorationing was defended by its advocates as an instrument of conservation of resources: "Its stated purpose is to avoid waste, which is defined as production in excess of market demand (at the going market price)" (Davidson, 1963, p. 96).

In reality, prorationing was more related to price-rigging and cartelization than to conservation. A bed-fellow of conservation, strangely enough, is monopoly. The immediate result of prorationing was an excessive drilling of development wells--at a cost of $500 million a year--at a time when existing wells were operating at a fraction of capacity. "For the individual producer sitting atop a known reservoir, the drilling of another development well promises an almost certain (only one in four to one in five development wells proves to be dry) additional ticket of admission to the cartel; it guarantees
an additional quota, at the rigged price, hence the possibility of a faster pay-out" (Kahn, 1964, pp. 307, 310).

Import quotas tend to hasten the exhaustion of the domestic crude oil stock (Hause, 1963, p. 408). In 1962, for example, the United States denied itself foreign oil which was $1.25 a barrel cheaper, in favor of 2.5 billion barrels of domestic crude. This, despite the facts that Middle East proved reserves were six times larger than ours and that their annual production was 1 percent of reserves whereas our annual production was 8 percent of reserves (Kahn, 1964, p. 310). Another result of the import quotas has been higher prices for both oil and oil-related products. It is possible, however, that the higher prices have encouraged exploration of oil lands which otherwise would have been submarginal (Davidson, 1964, pp. 130-1).

The issues of prorationing, import quotas, and monopolization are closely interrelated. State governments have in the past encouraged prorationing and the federal government has imposed import quotas, and both have resulted in a cartelization which could be broken if there were free import of foreign minerals: "If the suggestion seems too large-minded for American politics, recall that mercantilism, surely a small-minded philosophy, traditionally welcomes the import of crude raw materials. It is their export which stamps one a colonial" (Gaffney, 1967, p. 407).

4. Rule of Capture and Unitization

The "rule of capture," according to common law, enables the owner of a reservoir to drill and recover the fluids or steam contained therein even though they came from a neighbor's reservoir (Davidson, 1963, p. 94). This kind of situation provides a classic example in economics of what is called an externality where marginal private costs are less than marginal social costs. The rule of capture encourages excessive production from such common-pool
reservoirs and depletion is accelerated. The source of the problem is the imperfect ownership which also causes a wasteful duplication of efforts in the attempts of the various owners to reduce the resource to possession (Vickrey, 1967, p. 317).

The rule of capture discourages exploration for oil, gas, and geothermal resources because the prospector confers potential benefits to neighboring landowners for which he cannot charge a fee. The market place offers the prospector inadequate inducement to undertake socially desirable exploration (McDonald, 1967, p. 274) and a government subsidy program to wildcatters is one possible remedy for this market imperfection (Vickrey, 1967, p. 327). Another (partial) remedy is a joint venture arrangement whereby both expenses and benefits are shared. A more general remedy is unitization or collective operation of a reservoir.

Compulsory unitization eliminates "the insanity of competitive exploitation of the individual reservoir" (Kahn, 1964, p. 303). The principle of unitization is recognized by both federal and state laws. Section 18 of the Federal Geothermal Steam Act of 1970 (Public Law 91-581), for example, provides for both voluntary and compulsory unitization:

"For the purpose of properly conserving the natural resources of any geothermal pool, field, or like area, or any part thereof, lessees thereof and their representatives may unite with each other, or jointly or separately with others, in collectively adopting and operating under a cooperative or unit plan of development...

"[The Secretary of the Interior] may include in geothermal leases a provision requiring the lessee to operate under such a reasonable cooperative or unit plan, and he may prescribe such a plan under which such lessee shall operate, which shall adequately protect the rights of all parties in interest..."
5. Severance Taxes and Royalty Payments

The economic effect of severance taxes varies according to the method used to determine the tax base. There are three general types of severance taxes:

(1) Ad valorem in situ taxes have a tax base which is the value of the resource in the ground and are essentially a form of property tax.

(2) Ad valorem ex situ taxes have a tax base which is the value of the resource currently produced. This type of tax is also known as a sales, ad valorem severance, commodity excise, or royalty tax.

(3) Specific severance ex situ taxes have a tax base which is the physical quantity produced. Such production taxes are calculated as so many dollars per ton, gallon, or other physical unit.

A tax is considered neutral if it does not affect relative prices or production. Although the ad valorem in situ tax (if taxed at the same effective rate on all competing resources) is the only type of severance tax which is in this sense neutral, it is a tax that is rarely levied because of the extreme difficulty and controversy which accompanies attempts to determine the tax base. The other kinds of severance taxes are "a discriminatory burden on the exploitation of natural resources" (Vickrey, 1967, p. 322).

Ex situ severance taxes have the following effects:

- Prices are increased
- Production decreases
- Profitability declines
- Short-run conservation is aided by the decline in current production but an offsetting consideration is the premature abandonment of marginal operations
- Long-run conservation is impaired by the decline in profitability which discourages exploration.
The extent to which prices will rise and production reduced depends on the elasticities of the supply and demand curves of the firm. Figure 1, "Pre-Tax Situation, Demand and Supply," shows a firm with a rising marginal cost (MC) curve and a downward-sloping demand (D) or average revenue curve and marginal revenue (MR) curve.

In the pre-tax situation, the profit-maximizing firm produces 160 units at $2400 per unit so that total revenue is $384,000. Total variable costs are $64,000 and, assuming $200,000 in fixed costs and $1,000,000 invested, profits are $120,000 and the rate of return on capital is 12 percent.

If a 10 percent severance tax based on value of production is imposed, profits will be maximized if production is reduced to 156.5 units—a decline of 2.19 percent—with a new price per unit of $2435, an increase of 1.46 percent. Total operating costs will be $99,357 (of which $38,110 is the tax cost) and profits will decline to $81,739. The rate of return on capital will fall from 12 to 8.2 percent, a decline of 32 percent.

The firm depicted in Figure 1 had a moderately elastic demand curve; the price elasticity—percentage change in quantity divided by percentage change in price—was -1.5. If demand had been less elastic, the firm could have shifted more of the tax forward to the consumer by way of higher prices. The general result, however, remains the same: the imposition of ex situ severance and royalty taxes have immediate effects of raising prices and reducing both production and profitability. Production of firms remaining in business declines—there is a reduction in the intensive margin—and production from marginal firms ceases—there is a reduction in the extensive margin. The first effect (of reduced production) aids conservation but the economic annihilation of marginal firms runs counter to conservation. Investment in renewal of the resource through exploration, discovery, and development will decline because of the reduction in profitability.
FIGURE 1
Pre-Tax Situation: Demand and Supply

[Graph showing demand and supply curves]
6. Property Taxes

The present value of a natural resource can be estimated by capitalizing its future net income payments. A capitalized-value property tax at a percentage rate $r$ has the same impact on the value of the resource and the schedule of production as an increase in the rate of discount of $r$ percentage points (Hotelling, 1931, p. 164). Hence such a tax encourages increased production and shorter lives for resources. Some resource economists have thus suggested that the property tax accelerates depletion because the taxpayer is able to reduce the tax base by exhausting it (Vickrey, 1967, p. 323). The extent to which this is true depends at least in part on the degree of monopoly: "If, on the other hand, mineral resources are controlled by firms with monopoly power which retard current output in order to enhance prices, it is possible that a substantial property tax on mineral deposits in place will cause the monopolist to increase current output rates, with a consequent lowering of prices" (Steele, 1967, p. 245).

Property taxes may also serve the useful purpose of inducing utilization of properties being held idle for speculative purposes and may "bring down the market price of leases to explore superior land, lessening the financial burden of entry, opening the door to large numbers of small firms... The immediate impact of the property tax is on landowners, holdouts who have not yet signed leases" (Gaffney, 1967, p. 406).

A practical administrative problem with capitalized-value property taxes lies in assessment. Some assessors may base estimates of capitalized value on initial production rates and, to the extent this is the case, production in early years is curtailed. Also, some states base property tax assessments on current production and when this happens the tax is more like a severance tax which retards production.
Although the federal government can levy property taxes, it has rarely done so. Any federal property tax, according to the Sixteenth Amendment, must be apportioned among the states by population and this has been done only five times since 1789 (Gaffney, 1967, p. 402). A major appeal of the property tax is its ready availability to state and local governments wishing to accelerate their economic development.

7. Depletion Allowances

Percentage depletion allowances date back to 1926 when, in conjunction with a rise in corporate income tax rates to 13 percent, oil and gas producers were allowed to exempt 27-1/2 percent of their gross income from taxation. In the Reich Case landmark decision, geothermal steam at The Geysers, California was held to be a depletable gas and thus entitled to the same percentage depletion allowance available to any other oil or gas producer (1969 Tax Court of the United States).

The rate of percentage depletion was reduced in 1970, however, by the Tax Reform Act of 1969. As the law now stands, producers can deduct from taxable income the smaller of (1) 22 percent of gross income or (2) 50 percent of net income. Firms showing losses obtain no benefit from percentage depletion allowances because of the 50 percent of net income restriction. The net effective percentage depletion allowance for all firms averaged together has been estimated as being approximately 17.6 percent (Peterson and Seo, 1975, p. 12).

The real value of percentage depletion has risen over the years because of increases in the corporate tax rates. With a current corporate income tax rate of 48 percent, the percentage depletion provision makes each dollar of revenue worth 8.4 cents (.48 x .176) more than it otherwise would have been.
The economic effect of percentage depletion is the same as a negative excise tax (i.e., a subsidy) of 8.4 percent.

The key economic argument in favor of depletion allowances rests, surprisingly enough, not on the issue of depletion but rather on the issue of the nonneutrality of the corporate income tax. It is now generally although not universally accepted by resource economists that the corporate profits tax discriminates against risky and capital-intensive industries, such as oil and gas as well as geothermal. As a result of such discrimination (nonneutrality), relative profitability declines in such industries and investment funds flow elsewhere. Percentage depletion allowances serve a re-neutralizing role and help to restore the equity of the pre-tax situation: "on the basis of available data and certain reasonable assumptions, the present tax provisions applying to corporate income derived from oil and gas production seem to be consistent with allocative neutrality as between that industry and manufacturing, the latter taken to be the most logical standard of comparison" (McDonald, 1961, p. 336).

Elsewhere the present author has discussed the economic implications of depletion allowances (Peterson and Seo, 1975, pp. 18-26). Percentage depletion provisions have the following effects:

- an increase in production both in the short- and long-run
- an increase in exploration, discovery, and development
- a lowering of prices
- a short-run increase in profits which encourages new firms to enter the industry
- a long-run situation in which average rates of return are no higher than in other industries
- a Life Index (ratio of reserves to output) which tends to remain constant.
As a point of comparison, the above results are the opposite of the effects of a severance tax. This is as it should be since a percentage depletion allowance is an excise subsidy which is the opposite of an excise tax. Withdrawal of percentage depletion privileges would, moreover, have the same effects as the imposition of a severance tax.

Conclusions

General conclusions have been listed in the abstract. The preceding discussion has been based on resource exploitation in general and applies to such diverse assets as whooping cranes, herons, and coal mines. The emphasis, however, has been on the oil and gas industry. By virtue of the Reich case, geothermal steam production, at least at The Geysers, is legally a part of the oil and gas industry. Specific policy recommendations for federal, state, and local governments are as follows:

(1) It is desirable to institute a program of government subsidies or guaranteed loans for weakly-financed firms. This has the effect of lowering their rates of discount and will lengthen the lives of their resources.

(2) Severance taxes should be avoided since they result in both decreased production and decreased exploration, as well as higher prices. Such taxes represent a form of discrimination against resource development. In the example presented of a capital-intensive firm, a 10 percent severance tax reduced the rate of return on capital invested by 32 percent.

(3) Property taxes based on the capitalized-value of a resource are likely to encourage utilization of properties being held for speculative reasons and enable smaller-size firms to operate in the industry by bringing down the market price of leases.

(4) Percentage depletion allowances are a desirable means of restoring equity to risky and capital-intensive industries which are discriminated
against by the corporate income tax. A percentage depletion allowance is an excise subsidy and hence the opposite of an excise or severance tax. Any withdrawal of depletion allowances would have the same deleterious effects as an imposition of a severance tax.
Footnote

References


Hause, John C., "The Economic Consequences of Percentage Depletion Allowances," *National Tax Journal*, 16 (December 1963), 405-409.


