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# Lowering Real Interest Rates Could Slow Global Warming

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**Abstract.** *Carbon dioxide emissions from fossil fuel combustion have increased markedly in this century. Increased carbon dioxide concentrations in the atmosphere are thought likely to help produce a warming of global climate. Many strategies to reduce or reverse the anticipated global warming point to reductions of fossil fuel combustion as a primary ingredient. This paper examines the possibility of obtaining a decrease in world petroleum supply as a result of reducing interest rates relative to the rate of inflation.*

The likelihood that such a strategy might mitigate greenhouse warming is of particular importance in two ways to people on the Great Plains. First, the nature of regional climate change in the context of global warming is uncertain. The Great Plains agricultural system would surely have to adjust, though. Second, petroleum is especially vital for irrigation, cultivation, and transportation of crops, as well as for space heating in harsh winters. A decrease in petroleum supply would probably work an unusual hardship on people living on the Great Plains, but such hardship might be largely offset if it came as a byproduct of reduced real interest rates (interest rates minus expected inflation rates). Lower real interest rates would reduce the cost of farming, raise land values, and perhaps even improve demand for America's agricultural exports. From the viewpoint of the Great Plains then, slowing greenhouse gas emissions originating from petroleum by means of reducing interest rates relative to inflation rates would be, if it worked, an excellent "no regret" policy, probably superior to reducing petroleum consumption through regulation and taxes.

Adelman (1990, pp. 5,7) observed "Many respected names can be cited in support of the proposition that the higher the interest rate, the faster is optimal [petroleum] depletion. . . . The price explosions of the 1970s have been explained as a competitive response to a drastic fall in discount rates." While Adelman challenged this view in his paper, the model he developed was sensitive to very low real interest rates. Adelman confined

his analysis to rather high interest rates and neglected the distinction between real and nominal interest altogether. Unlike Adelman, the following exposition will emphasize that petroleum supply tends to increase when real interest rates are high and tends to decrease when real interest rates are low--especially when they get close to zero or drop below zero.

## Petroleum Supply

Interest rates and anticipated future inflation rates together help determine the optimum rate of extraction from petroleum reserves. Petroleum is different from many other exhaustible resources since the time of exhaustion is close for any currently producing reservoirs and the most important producers have very low extraction costs. The influence of interest and inflation reduces to the influence of the real rate of interest. It is my contention that a change in this variable seems theoretically sufficient to alter petroleum prices enough to bring on an energy crisis of the sort which emerged following the events of October 1973. Similarly, rising real interest rates partly explain the collapse of petroleum prices seen in the 1980s.

In order to understand the behavior of petroleum supply, economists identify the most rational course of action that might be undertaken by the owner of a petroleum reservoir. Hotelling (1931; see also Scott 1967; McDonald 1971; Adelman 1990) proposed the following model for exhaustible resources. Oil producers are expected to pursue their own self interest to the utmost. The oil producer is in possession of a valuable asset, the petroleum reservoir. The producer is in the process of exchanging this asset for another asset, perhaps an interest-earning bank account or a portfolio of securities. Since it will take time to trade off the petroleum reserves, the producer must consider the present value of the future proceeds from selling oil. Self interest is thought by economists to be best served by a plan designed to make the present value of his profits as large as possible.

The optimum rate of petroleum extraction at any time is part of a plan that maximizes the present value of a reservoir. If the rate of inflation dependably exceeded the rate of interest obtainable from invested profits, then cessation of production would maximize the present value of a reservoir. If the real rate of interest were small but not negative, then petroleum supply would decrease. In the model that follows, a seemingly small decrease in the real rate of interest is seen to alter substantially the optimum relationship between the price and the quantity supplied by oil producers. This effect alone could explain the price increases of 1974 and some of the large changes that occurred in more recent years.

### A Basic Model for Petroleum Extraction

To simplify the model, I ignore entry and exit from the industry and assume that the number of producing firms is fixed. For any particular firm, at any time $t$, the rate of extraction, ($q_t$), and the expected cost and revenue inflation rate ($\alpha$), determine the rate of receiving profit (or net revenue) per unit of time. Future profit in inflated dollars is calculated as:

$$nominal\ future\ profit = \pi(q_t)\,e^{\alpha t} \qquad (1)$$

I further assume that interest rate changes are unimportant in affecting real profit (or real net revenue) either because capital costs are small relative to revenue and other costs, or because capital costs are already fixed based upon some past interest rate. Demand for the natural resource is similarly treated as if unaffected by changes in the rate of interest; that is, as if substitute products' real prices were constant. The present value of profit from future oil production, using a nominal interest rate ($i$) to discount future profits, is:

$$present\ value = [\ \pi(q_t)\,e^{\alpha t}]\,e^{-it} \qquad (2)$$

The real rate of interest ($r$) discounts future profits measured in constant dollars. The real rate of interest is defined by collecting exponents in equation (2):

$$r = i - \alpha \qquad (3)$$

When $r$ is used, the expression for profits represents profits measured in deflated dollars.

The oil producer seeks to maximize the present value of the entire

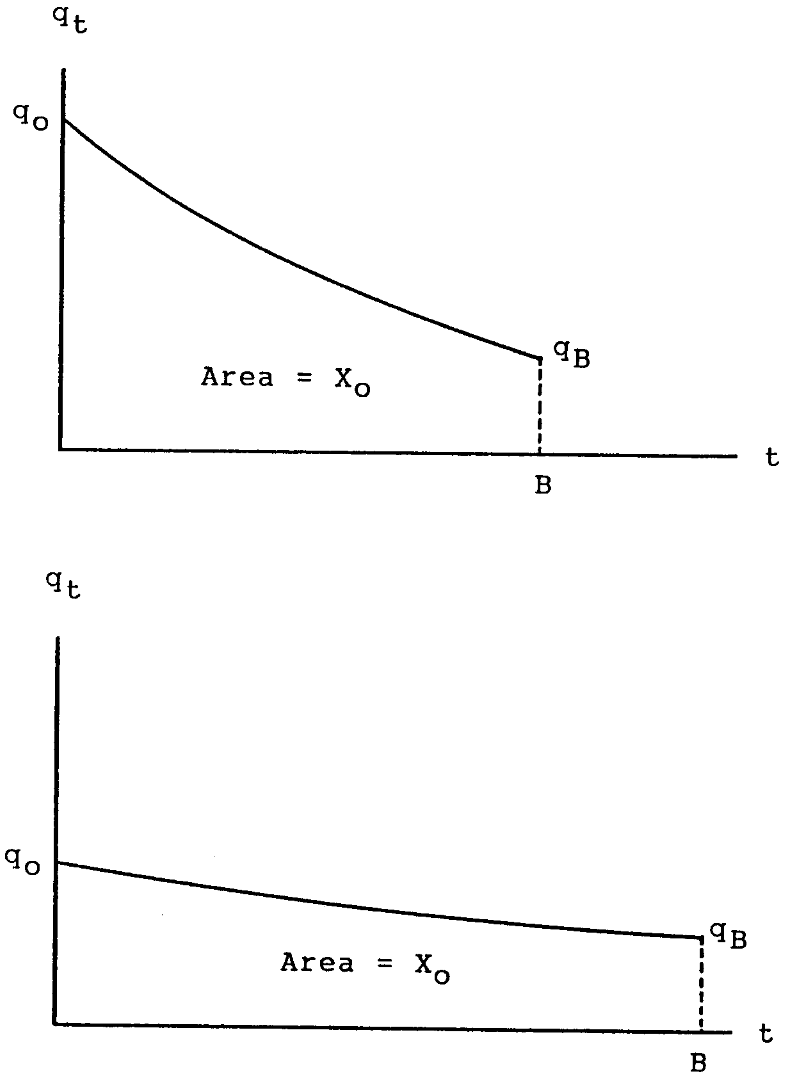


Figure 1. Extraction rate paths for high (top) and low (bottom) real rates of interest.

stream of profits received from the present to *B* years from now, when the total reserves ($X_0$) are exhausted. To do so, extraction should occur at rates that satisfy the following constrained maximization problem:

$$\text{maximize} \int_o^B \pi(q_t)\, e^{-rt}\, dt \tag{4}$$

subject to

$$x_o = \int_o^B q_t dt \tag{5}$$

The unknowns of the system are *B* and $q_t$.

Except for incorporating expected inflation, equations (4) and (5) are the traditional theory of exhaustion in its elementary form, corresponding to Hotelling's "monopoly case" (Hotelling 1931, 146-48). The model is applicable to the firm in the short run regardless of industry structure, however, because the profit function is not specified and the possibility of entry or exit by other producers is ignored. It works just as well for a competitive firm as for a monopoly firm. The model represents an isoperimetric problem in the calculus of variations (Schulze 1974, 55); equation (5) is termed an "isoperimetric constraint" (Kamien and Schwartz 1981, 43-47). The problem's solution requires that the following Hamiltonian function be at a maximum with respect to $q_t$ for any time before exhaustion (Schulze 1974, 54-58):

$$H = \pi(q_t)\, e^{-rt} - \lambda q_t \tag{6}$$

Equation (6) is at a maximum when its derivative with respect to $q_t$ equals zero. The following condition is necessary:

$$\pi'(q_t)\, e^{-rt} - \lambda = 0 \tag{7}$$

$\pi$ indicates the derivative of the profit function. A transversality condition is also necessary to determine $q_t$ and $B$:

$$\pi'(q_B) = \left(\frac{1}{q_B}\right) \pi(q_B) \tag{8}$$

Equation (8) locates the terminal rate of extraction by requiring that, in the end, marginal and average profits be equal--that is, the last unit be extracted so as to maximize its value at time $B$. Without the transversality condition, there are simply too many unknowns and not enough equations to determine them (Kamien and Schwartz 1981, 53-60). The transversality condition specifies that near the end of the life of a reservoir, the optimal strategy is to extract at a rate that maximizes per barrel profit; virtually no future remains to discount then.

A reduction in the present rate of extraction ($q_0$) results from a decline in the real rate of interest. The system of equations (5), (7), and (8) defines the extraction rate path (Fig. 1). Marginal profits increase through time at a rate equal to the real rate of interest, corresponding to an increasing difference between marginal revenue and marginal extraction cost because the extraction rate ($q_t$) is decreasing (equation (7)). The terminal rate of extraction comes from equation (8) and the area under the rate path curve comes from equation (5). A decline in the real rate of interest flattens out the extraction rate path curve by pulling down the optimum rate of extraction in the early part of the oil producer's plans (Fig. 1). The terminal rate remains unchanged but takes longer to reach because the area under the flatter and longer extraction rate path curve must hold constant to satisfy equation (5). The optimum present rate of extraction likewise rises if the real rate of interest rises. Scott (1967, 32-40) developed this idea less formally in terms of nominal interest rates, but he assumed that the real rate of interest is constant and unaffected by inflation. The next section investigates the potential magnitude of these responses to changes in the real rate of interest.

### A Specific Cost Function

Demand and average cost curves are often portrayed as straight lines for simplicity (quantity being the independent variable). With unspecified slopes, such curves are not limited to any particular industry structure. Even an oligopolist might regard demand as linear if he expects all future price movements to be upward. If pure inflation were expected, linear demand and average cost functions would shift upward through time at a rate equal to the rate of inflation. But pure inflation cancels out of the model, leaving the real rate of interest and real per barrel profit (price, $P$, minus per barrel cost, $C$). Per barrel profit in constant dollars is a linear function of the extraction rate, $q_t$:

$$P_t - C_t = a - bq_t \tag{9}$$

If profit per barrel is multiplied by $q_t$, the result is profit per unit of time as a function of the extraction rate at any time, $t$:

$$\pi(q_t) = aq_t - bq_t^2 \tag{10}$$

The derivative of equation (10) makes (7) become:

$$(a - 2bq_t)e^{-rt} = \lambda \tag{11}$$

Substituting in (5) from (11) solved for $q_t$:

$$x_o = \int_o^B \frac{a-\lambda e^{rt}}{2b} dt \tag{12}$$

gives

$$X_o = \frac{aB}{2b} - \frac{\lambda}{2br}\,[e^{rB} - 1] \tag{13}$$

For $q_o$, (11) implies:

$$\lambda = a - 2bq_o \tag{14}$$

The transversality condition (8) is satisfied by $q_B = 0$ and this with (11) gives:

$$a = \lambda e^{rB} \tag{15}$$

Equations (14) and (15) give:

$$e^{rB} = \frac{a}{a-2bq_o} \tag{16}$$

Therefore:

$$B = \frac{1}{-r}\ln(1-\frac{2bq_o}{a}) \tag{17}$$

Substituting into (13) from (14), (16), and (17):

$$X_o=\frac{a}{2b}\left(-\frac{1}{r}\right)\ln\left(1-\frac{2bq_o}{a}\right)-\frac{a-2bq_o}{2br}\left[\frac{a-a+2bq_o}{a-2bq_o}\right] \qquad (18)$$

Simplifying (18):

$$-rX_o=\frac{a}{2b}\ln\left(1-\frac{2b}{a}q_o\right)+q_o \qquad (19)$$

From (9):

$$a=P_o-C_o+bq_o \qquad (20)$$

Substituting (20) for ($a$) in (19), and simplifying, results in the optimum present rate of extraction, $q_0$:

$$2rX_o=\left(\frac{P_o-C_o+bq_o}{b}\right)\ln\left(\frac{P_o-C_o+bq_o}{P_o-C_o-bq_o}\right)-2q_o \qquad (21)$$

## Sensitivity to Real Rate Changes

What would have happened if the world's oil producers each supplied oil in accordance with equation (21) and then the real rate of interest had fallen? I am using rough approximations here to illustrate the model. Saudi Arabia produced two billion barrels per year from reserves of 50 billion barrels, with an extraction cost of $0.85 per barrel in 1972. It sold the oil for $2.50 a barrel and possibly assumed that the real rate of interest was 2%. An iterative solution to equation (21) yields $b$ = .339277. What would have happened if the real interest rate had dropped to 0.3%? If world demand for petroleum had been perfectly inelastic, a price of about $10 per barrel would then have been necessary for Saudi Arabia to have been willing to sell two billion barrels per year. Otherwise, the Saudis

TABLE 1
SENSITIVITY OF EQUATION (21)

| $r$ | $P_0$ | $q_0$ |
|---|---|---|
| .10 | 1.58 | 3.74 |
| .09 | 1.59 | 3.61 |
| .08 | 1.61 | 3.48 |
| .07 | 1.65 | 3.32 |
| .06 | 1.69 | 3.14 |
| .05 | 1.76 | 2.93 |
| .04 | 1.87 | 2.68 |
| .03 | 2.08 | 2.38 |
| .02 | 2.50 | 2.00 |
| .01 | 3.83 | 1.46 |
| .009 | 4.12 | 1.39 |
| .008 | 4.50 | 1.32 |
| .007 | 4.98 | 1.24 |
| .006 | 5.62 | 1.15 |
| .005 | 6.52 | 1.06 |
| .004 | 7.88 | .95 |
| .003 | 10.13 | .83 |
| .002 | 14.65 | .68 |
| .001 | 28.22 | .48 |
| .0005 | 55.36 | .34 |
| .0001 | 272.50 | .16 |

The above values for $P_0$ result from keeping $q_0$ equal to 2; the above values for $q_0$ result from keeping $P_0$ equal to 2.50.

would have substantially cut their then present rate of extraction (as their low cost competitors would also have done). For various real interest rates, the corresponding prices that would maintain $q_0$ at two billion barrels per year can be calculated from equation (21) (Table 1). The equation can also be used to calculate the quantity that would result from holding $P_0$ constant at $2.50. For each value of $q_0$, $P_0$ is a function of $r$ in equation (21) (Fig. 2). This illustrates the power of real interest rate changes in shifting the individual supply curves of oil producers.

World petroleum prices increased very dramatically by the end of 1974--the world "energy crisis" following 1973. An estimate of the real interest rate is obtained by subtracting from the one-year Treasury bill rate the percentage increase in the Gross National Product Implicit Price

Deflator index by the following year (Table 2). This measure of the real rate of interest had fallen to zero by 1971 and, by 1972, it had reached a negative value of -1.7%. In 1973, the value was again negative at -2.1%, and persisted at that value through 1974. Thus, the real rate of interest had apparently fallen and remained quite low for a considerable amount of time prior to the so-called "energy crisis." The collapse of oil prices in the 1980s was similarly preceded by an apparent substantial rise in the real rate of interest. The swings in the real rate of interest preceded major shifts in petroleum prices and, therefore, the cause alleged by the above theory is indeed preceding its effect.

### Competitive Equilibrium with Entry and Exit of Producers

Hotelling (1931, 140) discussed competitive equilibrium in his classic paper: "Since it is a matter of indifference to the owner of a mine whether

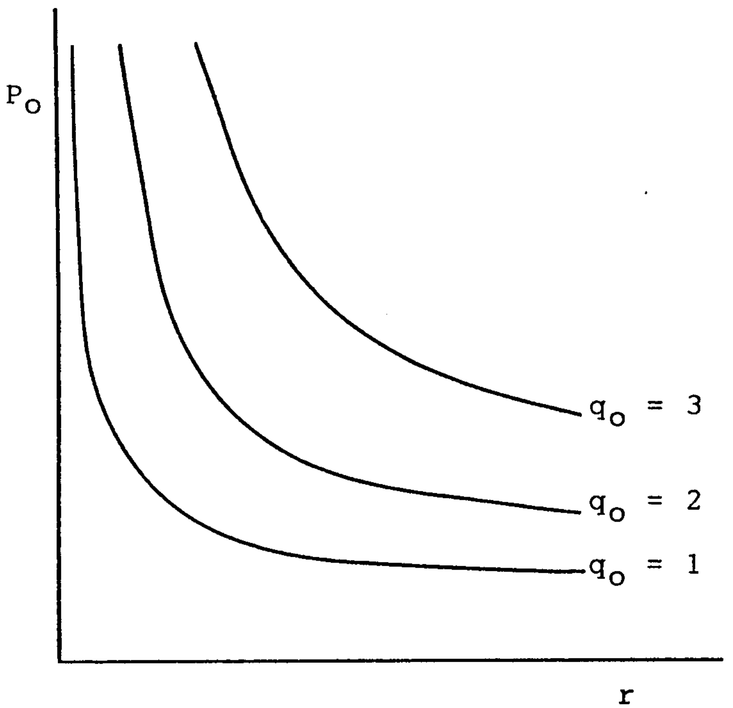


Figure 2. Family of curves generated by equation (21).

TABLE 2

| Year | (1) 1 Year T-Bill Yield | (2) GNP IPD Change by Next Year | (3) Real Interest Rate (1 - 2) | (4) Change in Crude Oil Price by Next Year |
|---|---|---|---|---|
| 1970 | 6.5 | 5.7 | 0.8 | 1.3 |
| 1971 | 4.7 | 4.7 | 0 | -6.0 |
| 1972 | 4.8 | 6.5 | -1.7 | 9.8 |
| 1973 | 7.0 | 9.1 | -2.1 | 83.7 |
| 1974 | 7.7 | 9.8 | -2.1 | 3.6 |
| 1975 | 6.3 | 6.4 | -0.1 | 0.9 |
| 1976 | 5.5 | 6.7 | -1.2 | -4.2 |
| 1977 | 5.7 | 7.3 | -1.6 | -4.6 |
| 1978 | 7.7 | 8.9 | -1.2 | 62.2 |
| 1979 | 9.8 | 9.0 | 0.8 | 157.1 |
| 1980 | 10.9 | 9.7 | 1.2 | 148.5 |
| 1981 | 13.1 | 6.4 | 6.7 | -91.1 |
| 1982 | 11.1 | 3.9 | 7.2 | -57.1 |
| 1983 | 8.8 | 3.7 | 5.1 | -21.8 |
| 1984 | 9.9 | 3.2 | 6.7 | -40.3 |
| 1985 | 7.8 | 2.6 | 5.2 | -181.7 |

Source: US Department of Commerce (1978), page 548 (1 year Treasury bill yield); (1980), page 607 (crude oil prices per million Btus); (1988), pages 446 (GNP IPD), 484 (T-bill), 542 (crude oil prices). Crude oil prices for 1971 and 1972 were converted from 1972 dollars to 1982 dollars using the GNP IPD.

he receives for a unit of his product a price $p_0$ now or a price $p_0e^{rt}$ after time $t$, it is not unreasonable to expect that the price $p$ will be a function of the time of the form $p = p_0e^{rt}$." Here, $p$ refers to the price net of the costs of extraction. Schulze (1974, 57) explained that, in equilibrium, the firm satisfies the necessary conditions for maximizing the present value of profits by producing at a constant rate equal to the optimum terminal rate $q_t = q_B$. The firm will produce at a constant rate where marginal cost equals average cost and average cost is at a minimum. Total industry output will decline through time because firms exit the industry, but the output of each individual firm will not decline through time.

With marginal and average cost equal because the firm is minimizing average cost per unit of output extracted, price net of average cost must rise at a rate equal to the rate of discount so that the time for starting

production will be a matter of indifference to the firm. If the rate of increase in price net of average cost were to fall below the rate of discount, then nonproducing firms would hasten to start production. Price would therefore immediately fall to a level from which it would rise more rapidly. Similarly, if price net of average cost were rising more rapidly than the rate of discount, each firm would wish to postpone producing and price would immediately increase to a level from which it would rise more slowly. An equilibrium time path for price therefore tends to be maintained by a sort of entry and exit of firms.

The response of such an industry to a change in the real rate of interest would be essentially the same as before. When petroleum fuel is gone and energy comes from coal, nuclear, and other "backstop" sources, petroleum will have given way to its "backstop technology substitutes." Given the real price that firms expect to prevail when the resource gives way to its backstop technology substitutes, the real rate of interest determines today's real price because it governs the curvature of the price path which ends at some fixed real level--the price at which users of the resource switch to their alternative energy sources. A rise in the real rate of interest would cause today's price to fall immediately and then rise gradually at a faster rate toward the backstop price. If the real rate of interest fell, today's price would immediately rise, but then it would continue to rise at a slower rate toward the "backstop price."

Eswaran et al. (1983, 154-67) argued incorrectly that such competitive equilibria do not exist in exhaustible resource markets with decreasing costs. Their conclusion rested, in part, on a contention that all firms in such an industry will begin producing at the same time. The fallacy of division (reasoning that what is true for the whole must necessarily be true for one part in particular) was made the basis for their proof. The authors reasoned that, since industry output will necessarily fall through time, at least one firm must be operating with its output falling through time. Schulze (1974, 57) identified a similar misconception promoted in other works on exhaustible resource industries.

## Empirical Findings

Because it involves expectations, the real rate of interest is not observable. However, the rational expectations hypothesis holds that expectations will not differ from optimal forecasts using all available information (Muth 1961). We might, at the risk of overextending the rational expectations hypothesis, assume that people do not consistently over- or underestimate the rate of inflation and therefore, the actual rate of inflation tends, on the average, to equal the rate that people expected before the fact. If a real rate of interest is calculated by subtracting the

percentage change by the following year in the GNP implicit price deflator from the average yield on one-year US Treasury bills, then regression results for the period 1970-1985 (Table 2) are as follows:

Real crude oil price change = 23.53 - 13.34 (real rate)
(19.64) (5.364)
(r = -.5536; standard error of estimate = 71.86)

The real crude oil price change for the United States by the following year is measured in constant dollars per million British thermal units. The standard error of the estimated real rate coefficient (5.364) gives a 95% confidence interval from -1.836 to -24.85 for the value of the population coefficient. The correlation indicates a moderately good fit, but it is negative and does suggest that petroleum prices respond to the real rate in the predicted direction. Nearly one-third of the variance is explained by the real rate of interest. Perhaps political events, foreign exchange movements, demand shifts, and so forth explain much of the remaining variance.

The change by the following year in the spot price of Mideast light crude-34 (measured in 1982 dollars per barrel--these units are smaller than million Btus) gives virtually equivalent results over the period from 1970 through 1985 (US Department of Energy 1988, Table 114):

Change in Mideast light = 2.38 - 1.188 (real rate)
(1.812) (0.495)
(r = -.5400; standard error of estimate = 6.627)

The standard error of the estimated real rate coefficient (0.4947) gives a 95% confidence interval from -.1264 to -2.249 for the population coefficient of the realized real rate.

Cecchetti (1986) estimated an expected real rate of interest that might be more satisfactory if the rational expectations hypothesis is not acceptable. He estimated an expected rate of inflation rather than using the actual rate. Regression of the changes in United States constant dollar crude oil prices over the time period from 1970 to 1985 with estimates derived from his graphs gives regression results very similar to those above with r = -.5462 for a real rate based on 3-month Treasury bills and r = -.3593 for a real rate based on 5-year Treasury notes.

The results of all these regression approaches suggest that when real rates have been low, crude oil prices have been rising, and when real rates of interest have been high, crude oil prices have been falling. The negative correlation might be further improved by lagging the changes or by estimating averages of current and past realized real rates of interest as a

measure of the expected real rate.

## Conclusions

Whether the price of an exhaustible resource will change in direct or inverse relation with changes in the rate of interest depends on the size of the resource stock and the importance of interest costs in producing its backstop substitute and in extracting the exhaustible resource (Farzin 1984). A reduction in the real rate of interest leads to a more rapid depletion of an exhaustible resource if the sum of the present values of capital requirements in producing its backstop substitute and in extracting the resource exceeds the present value of the resource stock (Farzin 1984, 848). If the existing stock of the resource is very large, then the price of the resource tends to equal its marginal cost of extraction. If the stock is very small, then the price tends to equal the price of its backstop substitute. In both of these cases, a reduction in the real rate of interest causes the price of the resource to fall. The size of the world's petroleum stock probably lies somewhere in between--a fact substantiated by the nonzero intercepts in the above regression equations. Capital costs in petroleum extraction vary greatly, depending on the reservoir.

In Saudi Arabia, capital costs for extracting crude are negligible relative to the price of crude. In Texas, capital costs are very close to the price of crude. This difference gives insight into the dramatic effects of the rise in real interest rates characteristic of the 1980s. Higher real interest rates increase the supply of crude coming from places like Saudi Arabia, thereby depressing world oil prices. At the same time, the rise in real rates decreases the supply from places like Texas by driving up the much more important capital costs of extraction there. The overall world petroleum market, however, seems clearly to respond by increasing the supply of crude when there is an increase in the real rate of interest. A reduction in the real rate of interest would reduce petroleum supply. A consequence of reduced supply might be reduced emission of carbon dioxide, and therefore a slowing of global warming.

Government policies to reduce real interest rates would probably emphasize reducing government borrowing and encouraging private saving. Admittedly, lowering real interest rates would have other effects beyond the petroleum market. Conceivably, lower real interest rates might somehow stimulate world production of goods and services in total, thus raising demand for petroleum at the same time supply is reduced. The desired reduction in petroleum combustion for the sake of mitigating global warming might thus fail to be achieved through interest rate strategies alone. However, in such a more robust world economy, additional policies to dampen petroleum demand would be more tolerable.

In the Great Plains, the question is how to reduce petroleum supply without ruining farmers and reducing the habitability of the region. The low real interest rates of the 1970s seemed to do the trick then, and might again in the future.

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